Performance Measurement Protocols:
Best Practices Guide

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Executive Summary

PURPOSE AND SCOPE

In 2010, ASHRAE published *Performance Measurement Protocols for Commercial Buildings* (2010a), which describes what to measure, how it is to be measured, and how often it is to be measured to quantitatively assess the performance of commercial buildings. This follow-on book is a working guide to help users implement the protocols outlined in *Performance Measurement Protocols for Commercial Buildings* by providing tools and techniques for measuring, managing, and improving the performance of a facility, as demonstrated by its energy and water use and indoor environmental quality (IEQ). Thus, it provides best practices for facility managers and operators to evaluate and improve the performance of commercial buildings throughout their service life. It is also intended to support integrated commissioning, as implemented in the existing building commissioning, or retrocommissioning, process, and all activities of the building's operation and maintenance team.

This Guide presents step-by-step procedures at three process levels of performance, which are intended to match the level of cost and intensity of effort for a range of types and sizes of facilities:

- *Basic Evaluation* is the basic, indicative level that uses observations of building characteristics, perceptions of occupants, and data from utility bills to characterize performance.
- *Diagnostic Measurement* is the intermediate level that uses physical measurements to diagnose problems indicated at the Basic Evaluation level and to characterize performance relative to physical standards so as to identify how performance can be improved.
- *Advanced Analysis* is the advanced level using the results of the first two levels plus the results of professional investigative processes to characterize performance and identify specific actions for performance improvement.

This Guide covers all facility energy-using systems, water-using systems, and systems that affect IEQ, as well as the measurement and operating techniques for energy and water conservation and IEQ improvement. It provides guidance, tools, and aids for building facility mangers, operators, technicians and consultants to continuously monitor and improve facility performance, including measurement and instrumentation details, specific procedures, and examples of forms, worksheets, and checklists in the appendices. The standardized forms, worksheets, and checklists are also available on an accompanying CD in Microsoft® Excel® format to simplify, facilitate, and expedite the process.

SUMMARY OF EVALUATION, MEASUREMENT, AND IMPROVEMENT PROCEDURES AT THREE LEVELS

Presentation of the evaluation, measurement, and improvement procedures begins in Chapter 1 with an introduction and overview of the process that applies at the three levels. Each level starts with the development of a plan then proceeds to a seven-step procedure (beginning with a flowchart) to implement that plan for the six measure categories of energy, water, thermal comfort, indoor air quality (IAQ), lighting/daylighting, and acoustics:

1. Collect building information
2. Conduct performance observation, measurement, and analysis
3. Conduct performance comparison (benchmarking)
4. Identify issues needing correction and take corrective actions
5. Remeasure performance
6. Compare new performance to past performance
7. Report results

The Basic Evaluation procedure is largely common to all six measure categories, with some items specific to each category. The reader should begin by applying this procedure for all categories to determine a baseline performance and to identify whether and where performance improvement should be pursued. The Diagnostic Measurement procedures will then identify what measurements should be taken to identify specific performance improvement opportunities. Finally, as indicated by results of the diagnostic measurements, specialists with particular expertise are engaged, as necessary, to conduct the investigative procedures in the Advanced Analysis.

A significant focus of this Guide is the relationship of the performance measurement process to existing building commisioning, as expressed in *California Commissioning Guide: Existing Buildings* (CCC 2006) and *A Retrocommissioning Guide for Building Owners* (PECI 2007) as well as the forthcoming ASHRAE Guideline 0.2, *The Commissioning Process for Existing Building Systems and Assemblies* (n.d.). The commissioning process is described in Chapter 1 of this Guide and includes a description of how the steps in the book's Building Measurement Process relate to the phases of existing building commissioning: planning, assessment, investigation, implementation, hand-off, and ongoing commissioning. Notes to the commissioning team are interspersed throughout the Guide to provide guidance at each step.

BASIC EVALUATION LEVEL

Chapter 2 presents the step-by-step Basic Evaluation procedures for energy and water, followed by the procedures for all four IEQ categories (thermal comfort, IAQ, lighting/daylighting, and acoustics). Figure 2-1 provides an overview of the Basic Evaluation level by category.

Each section is structured with an introduction, a description of the procedure, and a list of tools and aids. Standard reports and display graphs are presented for each category, and forms and spreadsheets are provided in the appendices and on an accompanying CD to simplify, facilitate, and expedite the process.

For energy the goal at this level is to reduce energy consumption and cost through the elimination of wasted energy and the improvement of system and equipment operation. Measurement focuses on energy bill analysis and a facility walk-through inspection (ASHRAE Level I energy audit [ASHRAE 2011b]) to identify obvious energy waste and low-cost or no-cost improvements; no additional measurements are conducted. This level does not require an outside specialist or professional but can be performed by building personnel with the steps and tools provided in this Guide.

At this level, lower water performance is achieved by eliminating water leaks or wasted usage, by improving the efficiency of plumbing fixtures, and by reducing the water used for landscaping. Utility water meters are used to verify performance.

For IEQ, recommended activities provide building personnel with advice and tools for determining whether perceived IEQ is adequate and whether there are deficiencies that can be corrected without the need for physical measurements. However, in certain situations the reader will be directed to the Diagnostic Measurement and/or Advanced Analysis level where, with some exceptions, the services of an IEQ professional are needed. A discussion of the complexities of environmental factors and their interactions is included.

Because many of these activities are common to all four IEQ categories, they are presented in general terms, with specific reference to aspects that are unique to each category. Evaluation activities include occupant surveys and field observations, presented for each of the IEQ categories. Field observations are gathered via a building walk-through. A walk-through form, including checklists and recommended corrective actions, is shown in Appendix A and included on the companion CD.

Observations, measurements, and analysis, as well as corrections or adjustments to improve performance, are given for the following:

Thermal Comfort
- Fenestration
- HVAC systems
- Other systems

IAQ
- Ventilation
- Moisture management
- HVAC systems
- Building envelope/pressurization
- Dirt or contamination

Lighting/Daylighting
- Quantity/quality of light
- Glare
- Controls
- Lamps and ballasts
- Maintenance

Acoustics
- Background noise
- Noise intrusion
- Acoustic privacy
- Speech communication

DIAGNOSTIC MEASUREMENT LEVEL

Chapter 3 presents the step-by-step procedure at the Diagnostic Measurement level.

Energy performance measurements include submetering of major end uses and specific components, along with the equivalent of an ASHRAE Level II energy audit (ASHRAE 2011b). Data is analyzed over shorter time intervals, typically monthly, weekly, or daily, sometimes supplemented by hourly or subhourly data, if available. Data normalization for weather (degree-days) and/or occupancy is described and examples of electric and gas use correlations are given. The energy audit task requires the use of physical measurement and instruments, augmented by calculations, by a person experienced in energy use and cost analysis measures. Target energy reduction goals are set and energy efficiency measures (EEMs) having a simple payback of three to five years are identified.

Water measurement protocols at this level use the same procedures as in the Basic Evaluation but add weather and occupancy normalization. Submeter readings may be used to identify nonsanitary water use and areas for performance improvement. Measurements are taken from utility or local monthly water meter readings, primarily representing sanitary water use; landscape water use is separately accounted for and normalized per landscape area. Process loads are separately metered at the Advanced Analysis level but are included with the landscape water at the Diagnostic Measurement level. Guidance is given for repairing leaks, determining savings from replacement with more efficient fixtures, and reducing landscape water flows and times of application.

For thermal comfort, physical measurements are taken in areas having problems as well as in control areas without problems to diagnose the causes and the extent of performance problems identified during the Basic Evaluation. Corrections are proposed and, once implemented, their effectiveness is tested by repeating the measurements. The people doing the work might be building staff, HVAC contractors, design engineers, or appropriately qualified consultants.

Performance observation establishes the location and basis of identified issues. Focus is on a detailed examination of thermal comfort survey results and observation of occupant actions, e.g., permanently lowered window shades, cardboard over windows, taped diffusers. This may be followed by spot measurements of functional flaws, including high velocities from diffusers or excessive thermal gradients, etc. These are generally taken with handheld or tripod-mounted instruments. Time-series measurements of temperature, humidity, and air velocity may record the thermal environment and HVAC system performance, allowing intermittent or transient effects to be captured. Data is benchmarked against comfort criteria in ANSI/ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2010b).

For IAQ, building data should be gathered to identify the locations and causes of problems not only where problems have been identified by occupant surveys or complaints but also in control areas for comparison. Measurements are not conducted at this level. If IAQ problems are confirmed but cannot be remedied by simple measures, users are recommended to the Advanced Analysis level, where an expert is retained to investigate.

<u>If there are no problems, the building should be benchmarked against the ventilation criteria in ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2010c). Outdoor air rates should be measured for each ventilation system; rates are logged with the building automation system</u>

(BAS) and compared to setpoints to ensure that minimum flow is maintained. Minimum outdoor air rates should be compared with the design values. Ventilation airflow sensors are calibrated and demand control sequences are tested annually. Room humidity is measured under nonheating conditions to ensure that the room relative humidity is less than 65%. Toilet and other exhaust airflow directions are tested to ensure that air flows into, and not out of, the toilets. Pressure drop on particle filters is measured and filters are changed as specified in the maintenance manual.

For lighting/daylighting, Diagnostic Measurement involves gathering additional building data, conducting a lighting audit, and making lighting measurements. These activities can be conducted by properly trained in-house personnel or may require the use of an outside professional with lighting/daylighting expertise. Using the results of the Basic Evaluation, spaces are identified that need point-by-point illuminance measurements. Two types of building data need to be collected: space details and lighting audit details. Illuminance measurements should be made on work planes or on room surfaces where issues of luminance ratios or glare are important. The results of these measurements can be compared against lighting recommendations in *The Lighting Handbook* (IES 2011). In some cases it may be possible for in-house personal to add or move luminaires. However, in most situations it is best to proceed to Advanced Analysis where design issues are considered.

For acoustics, Diagnostic Measurement measurements are taken to diagnose the extent of dissatisfaction identified in the Basic Evaluation. Building operators and owners without personnel skilled in sound level measurements should proceed to the Advanced Analysis level and seek outside professional services.

Dissatisfaction related to background and intruding noise typically requires additional sound level measurements. Building data need to be gathered only for occupied spaces where acoustic issues have been identified. If speech intelligibility is an issue, such as in classrooms or conference rooms, the room dimensions and surface material characteristics are needed for the reverberation time calculation.

A-weighed equivalent sound levels (L_{eq} in dB(A)) are measured in the spaces identified by the occupant survey using instrumentation equivalent to an integrating sound level meter. Tables of recommended sound pressure levels are provided as benchmarks. The measurement of room reverberation is best performed by someone skilled in acoustic measurements. However, a simple diagnostic assessment of the space is possible by calculation of the reverberation time based on the room volume, surface finishes, and room furnishings.

ADVANCED ANALYSIS LEVEL

Chapter 4 presents the step-by-step procedure at the Advanced Analysis level.

The Advanced Analysis energy performance evaluation focuses in depth on specific systems and equipment at higher levels of granularity (i.e., hourly or 15 min interval data, etc.) to determine the location and cause of energy use problems. Many of the recommendations resulting from this analysis will involve modifications to BAS programming and components. The approach is to collect detailed interval data on building systems and equipment and to compare that data to self-reference benchmarks that indicate how the systems and equipment should be operating in the specific application or operational context.

The first step is to engage a consultant to identify which systems are to be monitored and how. Data to be collected can include operating temperatures and setpoints, airflows, equipment statuses, valve and/or damper positions, variable-frequency drive (VFD) speeds, etc. Metering points may be permanent as included in the energy management and control system (EMCS) or BAS, may be web-based meters or included in the power management system, or may be data loggers or manually read meters. Software that will be used for analysis (i.e., manual or automated approach) is determined. Connecting remotely to the site EMCS/BAS system to download data files is a common way to collect the data needed. However, if remote access cannot be arranged, data can be downloaded manually and made available through a variety of electronic methods. Several examples are given in Appendix E.

An Advanced Analysis water assessment involves taking detailed water use readings and involves advanced usage analysis, normally employing a specialist or consultant. Submeters and advanced normalization techniques are used to improve the granularity of the readings. The following activities are addressed at this level:

- engagement of a specialist to accomplish the plan,
- identification of a specific target for water reduction, and
- creation of a list of submetering, such as cooling tower and boiler makeup water, kitchen and other process water, subdivided landscape areas, cleaning water, and recycled and/or harvested rainwater.

Normalization parameters and benchmarks are established for each of these submetered flows. Data analysis calculations are presented for leak rates, plumbing fixture water use, cooling tower water use, and landscape water use. Finally, recommendations for water use improvement, and related calculations, are presented.

To optimize thermal comfort performance one must take advantage of all the thermal elements available in the indoor environment as well as the behavioral responses of the occupants. The Advanced Analysis thermal comfort section presents such elements, as incorporated in ASHRAE Standard 55 (2010b). To address these elements, the following strategies are discussed in detail:

- Adjusting thermostat and supply air temperature dead-band setpoints for climate-adaptive, seasonal comfort, including air movement cooling and radiant heating
- Providing local thermal comfort control options
- Reducing excessive minimum supply air volumes
- Controlling direct sunlight in work areas
- Controlling humidity independently of supply air temperature

The IAQ methods and measures for Advanced Analysis should be implemented with the help of an IAQ professional. If Basic Evaluation or Diagnostic Measurement evaluations indicate that further study is needed, it will probably take the services of an industrial hygienist. If mold was identified, if there are non-obvious sources of odors, or if occupant complaints are recorded that could indicate sick building syndrome (SBS) or multiple chemical sensitivity (MCS), a firm that specializes in these areas should be hired. Potential contaminants of concern (CoC) in the indoor air are diagnosed and remediated by an IAQ specialist, as needed. Environmental measurements should be attempted only if contaminants are known or suspected and if there is a specific plan for using the measured data.

Factors to consider for indoor chemistry and biocontaminant measurement baseline and analysis are presented, emphasizing key points regarding environmental monitoring of IAQ that are taken from *Indoor Air Quality Guide: Best Practice for Design, Construction and Commissioning* (ASHRAE 2009a).

At the Advanced Analysis level for lighting/daylighitng, recommended activities require the services of a professional with lighting/daylighting expertise. Elements of a walk-through checklist review and development of an improvement plan are presented, including criteria for the engagement of a lighting professional. The review should include the types of instruments that are to be used; lighting instrumentation is discussed in Appendix I.

For lighting systems, performance measurement consists of surveying the building occupants regarding satisfaction with lighting/daylighting and using the Walk-Through Checklist in Appendix A for the portions of the building that have lighting issues. Areas that in the checklist could include the following:

- Lighting and control
- Daylighting methods and controls
- Visual acuity
- Methods of measurement
- Energy use

The Advanced Analysis level for acoustics is required in those situations where remediation is necessary but beyond the scope of the building operators, maintenance staff, or repair technicians. If the source of occupant dissatisfaction cannot be resolved by Basic Evaluation and Diagnostic Measurement corrective actions, then an acoustical consultant should be hired. Criteria for the selection of the consultant are given. It is recommended that the first task for the acoustical consultant be to review the data and findings of the occupant survey and the measurements from the Diagnostic Measurement level. This will likely include a precise assessment of the background noise and reverberation time in rooms where there is acoustic annoyance. Specifications and calibration requirements for octave band sound level meters are discussed in Appendix J. If the character of the background sound includes unusual or distracting sounds, such as tones or time-varying amplitudes, the consultant should conduct other diagnostic tests such as narrow-band FFT spectral analysis. The consultant should then recommend options to mitigate these problems, including estimated benefits and information from which costs can be derived.

The remainder of this Guide is devoted to a series of appendices that provide measurement and instrumentation details, specific procedures, and examples of forms, worksheets, and checklists in the appendices. The standardized forms, worksheets, and checklists are also available on an accompanying CD in Microsoft Excel format to simplify, facilitate, and expedite the process.

Preface

BACKGROUND

In the spring of 2010, ASHRAE published *Performance Measurement Protocols for Commercial Buildings* (2010a), a joint effort between ASHRAE, the U.S. Green Building Council (USGBC), and The Chartered Institute of Building Service Engineers (CIBSE) that identifies the items that should be measured to fully characterize and quantify building performance. It prescribes standard protocols for the measurement of building performance, describes how that performance should be measured (instrumentation and spatial resolution), and details how often it should be measured. It provides a standardized, consistent set of protocols for a range of costs/accuracies against meaningful and consistent benchmarks to facilitate the appropriate and accurate comparison of measured performance of buildings, especially those claimed to be green, sustainable, and/or high performance. For each of these measured characteristics, protocols are developed at three levels (hierarchy of low, medium, high) of cost/accuracy, providing realistic choices for consistent performance characterization of the building stock and comparison to appropriate benchmarks.

That book was the culmination of a five-year process that began with the completion of an extensive literature evaluation of performance measurement activities, conducted by Nexant, Inc., which surveyed and analyzed more than 400 documents (McNeill et al. 2007.) Based on that survey, *Performance Measurement Protocols* (ASHRAE 2010a) was written by a committee of industry experts to present protocols and procedures for the performance measurement of commercial buildings that included energy use, water use, and indoor environmental quality (IEQ), which consists of thermal comfort, indoor air quality (IAQ), lighting/daylighting, and acoustics.

A follow-up best practices guide was recommended to implement the above protocols by providing processes and tools that would make measurement, verification, and correction easier for facility managers and operators. This *Performance Measurement Protocols: Best Practices Guide* (referred to herein as "the Guide") distinguishes three levels of performance intended to match the levels of cost and intensity of effort for different types and sizes of facilities:

- *Basic Evaluation* is the basic, indicative level that uses observations of building characteristics, perceptions of occupants, and data from utility bills to characterize performance.
- *Diagnostic Measurement* is the intermediate level that uses physical measurements to conduct diagnostic analysis of problems indicated at

the Basic Evaluation level and to characterize performance in relation to physical standards so as to identify how performance can be improved.
- *Advanced Analysis* is the advanced level using the results of the first two levels plus the results of professional investigative processes to characterize performance and identify specific actions for performance improvement.

These levels are described in detail in Chapter 1.

PURPOSE, SCOPE, AND INTENDED USERS

The purpose of this book is to serve as a working guide that provides tools and techniques for measuring, managing, and improving the performance of a facility, as measured by its energy and water use and IEQ. It is intended to be used to support integrated commissioning, as implemented in the existing building commissioning (retrocommissioning) process (CCC 2006; PECI 2007), as well as all activities of the building's operation and maintenance team.

It implements the protocols presented in *Performance Measurement Protocols for Commercial Buildings* (ASHRAE 2010a) by prescribing specific sequences of tasks for implementing the protocols. These tasks will first help to identify, through recommissioning, where tune-up operational changes are needed to improve performance. These operational changes are especially addressed at the Basic Evaluation level, which includes extensive use of occupant surveys, operator and management interviews, and observations. Basic Evaluation also provides guidance for corrective actions not requiring engineering or cost analysis. While Diagnostic Measurement and Advanced Analysis are later used to identify hardware upgrades, specific implementation actions are beyond the scope of this Guide. Comprehensive identification and implementation of energy efficiency measures (EEMs) are addressed in *Energy Efficiency Guide for Exiting Commercial Buildings: Technical Implementation* (ASHRAE 2011a). Note that the business case for rigorous energy efficiency improvement action is presented in *Energy Efficiency Guide for Existing Commercial Buildings: The Business Case for Building Owners and Managers* (ASHRAE 2009b). The energy sections of this Guide should be used in conjunction with *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b) since many of the Basic Evaluation protocols are based on observations obtained using these energy audit procedures.

This Guide covers all facility energy-using systems, water-using systems, and systems that affect IEQ, as well as the measurement and operating techniques for energy and water conservation and IEQ improvement. It provides guidance, tools, and aids for building facility mangers, operators, technicians, and consultants to continuously monitor and improve facility performance, including measurement and instrumentation details, specific procedures, and examples of forms, worksheets, and checklists in the appendices. The standardized forms, worksheets, and checklists are also available on an accompanying CD in Microsoft® Excel® format to simplify, facilitate, and expedite the process.

The primary users of this Guide will be facility managers, building operators, commissioning authorities, tenants, green building raters, energy service companies, and architects and design engineers. The contents are written for these professionals; however, the book is also understandable to building owners, government officials and decision makers, and others with little technical background. Additional users include energy researchers interested in whole-building performance.

GETTING STARTED

This Guide covers the following measure categories:

- Energy use
- Water use
- IEQ, which consists of:
    - Thermal comfort
    - IAQ
    - Lighting/daylighting
    - Acoustics

The Basic Evaluation procedure is largely common to all six measure categories, with some items specific to each category. The reader should begin by applying the Basic Evaluation procedures to all categories. This will determine a baseline performance and will identify whether and where performance improvement should be pursued. The Diagnostic Measurement procedures will then identify what measurements should be taken to specifically identify performance improvement opportunities. Finally, as indicated by the diagnostic measurements, specialists with particular expertise are consulted, as necessary, to conduct the procedures in the Advanced Analysis.

Introduction and Overview 1

EVALUATION, MEASUREMENT, AND IMPROVEMENT PROCEDURE

The need for objective and rigorous performance evaluation of a building, as well as the techniques and procedures that support such an evaluation, are often not understood or appreciated. First of all, while a building may appear to be performing well, this cannot be verified unless its performance is measured and compared to meaningful benchmarks on a regular and continuing basis. Second, while performance may initially be satisfactory, it will degrade over time unless it is continuously monitored and corrective actions are taken as necessary. Furthermore, to identify how to improve building performance, measurement and remeasurement of performance is necessary. While some readers may well understand this, they will need to convince skeptical building owners that they need to engage the procedures presented here.

Maintenance of peak building performance is essential to the economic interests of the building owner and operator. Performance improvements not only reduce utility bills and other operating costs, but indoor environmental quality (IEQ) performance affects occupant health, comfort, satisfaction, and productivity, which have considerable impacts on building personnel costs.

For each of the six measure categories covered in this Guide—energy use, water use, and the four IEQ categories of thermal comfort, indoor air quality (IAQ), lighting/daylighting, and acoustics—and at each level of measurement (Basic Evaluation, Diagnostic Measurement, and Advanced Analysis) a step-by-step process is presented to provide a systematic and easy-to-use structure for the evaluation, measurement, and continuous improvement of building performance. Improvement measures are suggested in a checklist format but implementation details for these measures are left to other documentation referenced in this Guide, e.g., *Energy Efficiency Guide for Existing Commercial Buildings: Technical Implementation* (ASHRAE 2011a).

Note that whereas all measure categories rely first on planning and on building walk-through observations to evaluate performance and note needed improvements, the IEQ evaluation begins with occupant surveys to assess performance. This is followed by measured data collection and its analysis, which in turn is followed by benchmarking against previous performance data or peer buildings. This forms the basis for operational, system, controls, or equipment adjustment and/or replacement to improve performance. This is followed by retesting to quantify and verify performance improvement, and then by the reporting of results. The procedure is described more fully in the following section.

EVALUATION, MEASUREMENT, AND IMPROVEMENT PLAN

After a commitment is made by building management to evaluate and improve building performance, the first step is preparation of a plan. This plan needs to describe the commitment of the facility owner and operator to the facility performance improvement process and protocols, including target setting, to actually make a difference in building performance. While its scope should first include a clear understanding of the objectives of the owner/operator and their priority ranking, the scope must include the interest of all stakeholders in the building's operation: owners, managers, operators, tenants, and occupants. However, the participation of the operation and maintenance (O&M) team is especially important because of their intimate knowledge of the building's operation. The plan needs to address the level of effort to be pursued in each of the six measure categories. Determining the level pursued may depend on the existing conditions of the facility, and different categories may be done at different levels. A template for this plan (Basic Evaluation Measurement Plan form) is included in Appendix A and in the Basic Forms Workbook on the companion CD.

PROCESS FOR EVALUATION, MEASUREMENT AND IMPROVEMENT

For each of the six measure categories the plan is followed by a seven-step procedure:

1. Collect building information
2. Conduct performance observation, measurement, and analysis
3. Conduct performance comparison (benchmarking)
    - To past performance (self-reference)
    - To baseline databases (peer buildings)
4. Identify issues needing correction and take corrective actions; see commissioning resources such as Building Commissioning Association's *Best Practices in Commissioning Existing Buildings* (BCA 2008), *California Commissioning Guide: Existing Buildings* (CCC 2006), *A Retrocommissioning Guide for Building Owners* (PECI 2007), and the forthcoming ASHRAE Guideline 0.2, *The Commissioning Process for Existing Building Systems and Assemblies* (n.d.), among others
5. Remeasure performance
6. Compare new performance to past performance
7. Report results

These steps address the measurement methods, metrics, and performance evaluation/benchmark characteristics described in *Performance Measurement Protocols for Commercial Buildings* (ASHRAE 2010a), but in greater detail. While this full process is appropriate for Basic Evaluation and Diagnostic Measurement, it is modified for Advanced Analysis since the focus there is on selection and management of specialist consultants. Tools and aids are presented to provide resources for implementation of the plan.

BENCHMARKING

There are two benchmarking processes for improving building systems' performance covered in this Guide. One is to compare facility system performance to past facility performance over time (self-reference). This involves the ongoing measurement of performance, making changes or adjustments, and then remeasuring the results. This functions as a building performance dashboard, giving continuous feedback on performance trends. Comparing the present results to past results on a regular basis provides an instructive, quantitative basis for continuous improvement. The second benchmarking process is to compare the current facility operating performance to industry databases of buildings of similar type, function, and size (peer buildings). This provides an understanding of the adequacy of current facility performance and the potential for improvement.

For the IEQ measures, the occupant survey serves as the Basic Evaluation source of performance measurement. This survey measures those factors that affect occupant productivity, which has significant cost implications for building management; comfortable and satisfied occupants tend to be more productive. Furthermore, surveys can be considered marketing tools to assess how well the owners/managers are performing as service providers to the occupants (customers).

Survey results need to be benchmarked against a database of previous responses that serves as the basis for analysis. All survey results are compared to the database to relate a building's performance to that of peer buildings. If desired, this comparison may be filtered by building type and other factors such as building size, function, age, or geographic region. If the survey is repeated over time in a given building, a trend of IEQ performance can be established. Such self-referenced evaluation serves to record the effects of the best practices commissioning process, as well as ongoing maintenance and operation of the building.

TOOLS AND AIDS

The CD accompanying this Guide provides standardized forms and spreadsheets and presents occupant survey questions and a summary of benchmarking average values, [[Lilas says: I think that the CD form being referenced here is not called an occupant survey but rather this references the walk-trhru checklists in the Basic Evaluation General Forms Workbook]] though in practice the survey procedures and data analysis may be most conveniently and inexpensively processed through a web-based service.

HOW COMMISSIOING RELATES TO PERFORMANCE MEASUREMENT AND IMPROVEMENT

High-performance buildings require that the building and its systems perform to their design intent, as documented in the Owner's Project Requirements (OPR) for new buildings or the Current Facility Requirements (CFR) for existing buildings; the process used to validate this performance is *commissioning* (*Cx*). For a building to operate at a high level of performance, each step in the building process must be performed correctly, including design, construction, initial Cx, and operation (including ongoing Cx). The performance protocols described in this Guide are key elements of the Cx process as shown in Figure 1-1.

While performance measurement is essential to Cx, Cx is broader in scope and includes other elements, such as assisting the owner in developing the OPR or

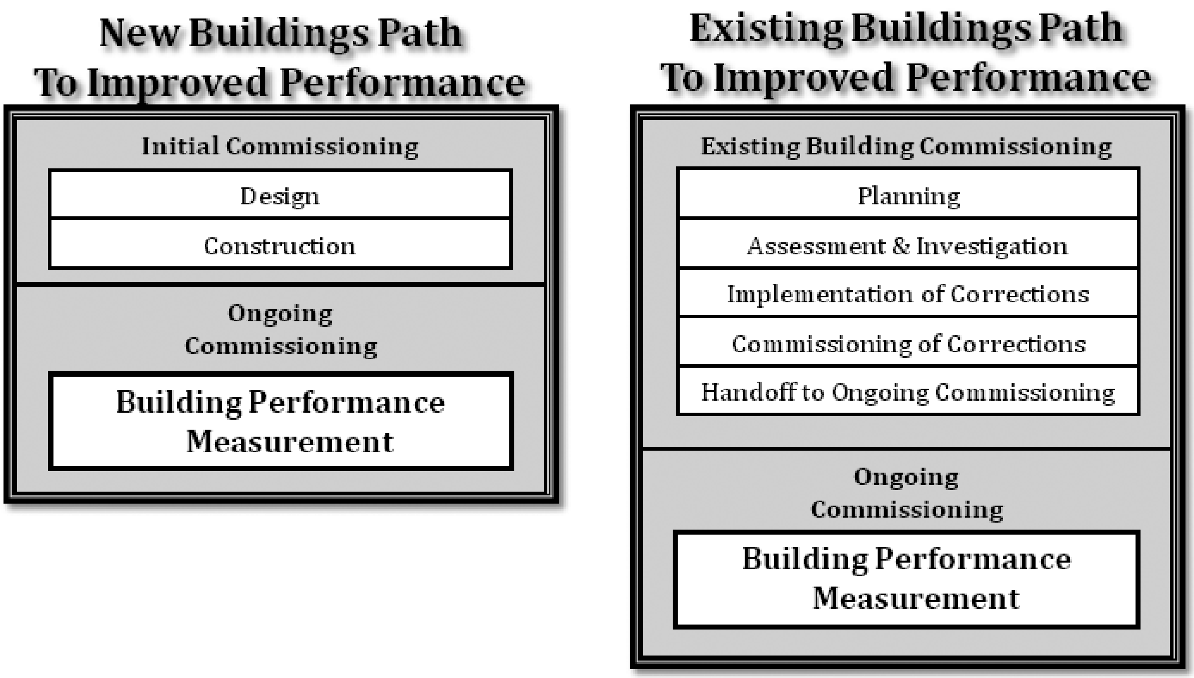


Figure 1-1 Contrasting Paths to Improved Performance for New and Existing Buildings

CFR and documenting that the design intent expressed in the OPR or the operational intent expressed in the CFR is met once the building is operational.

Cx begins with the design and construction of a building—this is sometimes called *initial commissioning*. After the building is in operation, adjustments and retrofits may be made on a continuous basis, typically conducted under existing building commissioning (EBCx) (CCC 2006; PECI 2007). Buildings that were constructed without Cx may be commissioned later, particularly during retrofit or renovation; this is called existing building commissioning (sometimes referred to as *retrocommissioning*). If a building was commissioned initially and is again commissioned at a later date, this is called *recommissioning*.

Ongoing Cx refers to a continuation of the Cx process periodically throughout the life of the building, as depicted in Figure 1-2. It includes measuring performance, analyzing the resulting performance level, making adjustments or changes for improvement, and then performance reevaluation. Note that performance evaluation transcends the narrower tasks of system acceptance testing by providing a basis for the continuous improvement of performance. While systems may pass acceptance testing during initial Cx, those systems tend to degrade with time and must be commissioned on an ongoing basis to maintain peak performance. Not only must systems operate as designed, but they must meet the satisfaction of the owner and occupants.

The process presented in this Guide supports EBCx as well as ongoing Cx, conducted by a commissioning authority (CxA) or Cx manager, by providing the measurement basis for continuous performance improvement. Therefore, the predesign, design, and construction Cx tasks related to initial Cx, as presented in ASHRAE Guideline 0, *The Commissioning Process* (2005), and ASHRAE Guideline 1.1, *HVAC&R Technical Requirements for the Commissioning Process*

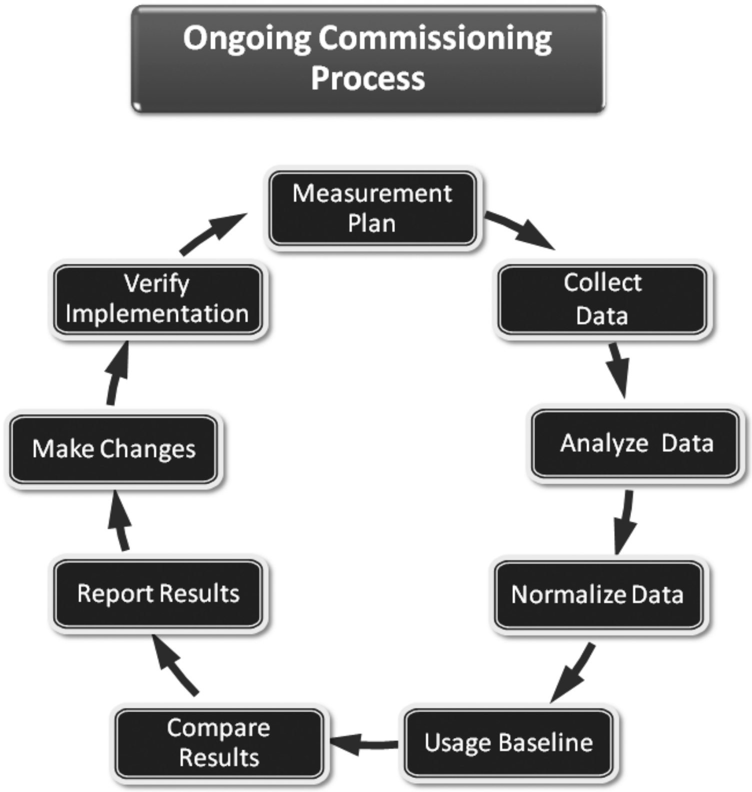


Figure 1-2 The Ongoing Commissioning Process

(2007a), are not included here. Figure 1-3 summarizes this basic building measurement process as it relates to Cx.

The performance measurement process of this Guide relates to the six phases of the EBCx process as defined in *California Commissioning Guide: Existing Buildings* (CCC 2006) and *A Retrocommissioning Guide for Building Owners* (PECI 2007) as well as the forthcoming ASHRAE Guideline 0.2, *The Commissioning Process for Existing Building Systems and Assemblies* (n.d.). The six phases of EBCx are as follows:

- *Planning Phase:* Development of the EBCx goals and facility requirements and an EBCx Program Plan for a portfolio of buildings.
- *Assessment Phase:* Development and definition of CFRs and an initial EBCx plan for a single facility.
- *Investigation Phase:* Field inspections, data gathering, testing, and analysis to assess (benchmark) accurately system performance, as compared with the owner's CFR, and identify improvement opportunities.
- *Implementation Phase:* The desired facility improvements are completed and the results and performance are verified.
- *Hand-Off Phase:* The systematic transition from a Cx activity and the Cx team to standard operating practice and the O&M team.
- *Ongoing Commissioning:* Implementation of systems and tools to support both the persistence of benefits and continuous performance improvement over time.

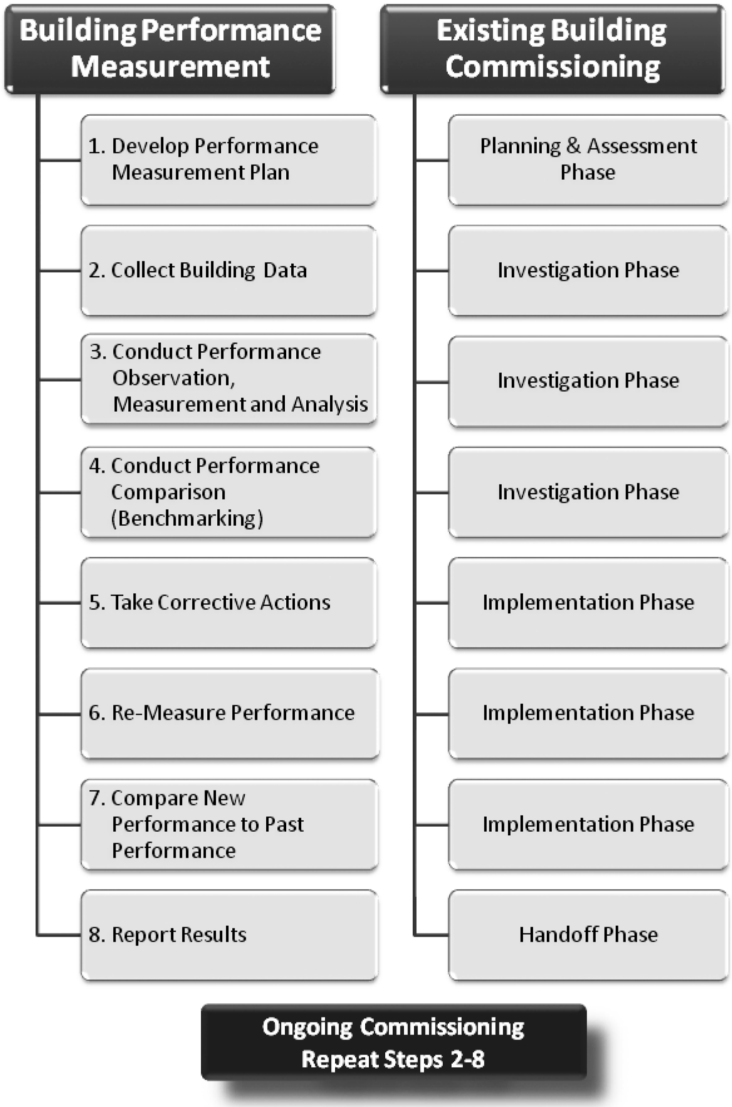


Figure 1-3 Steps in the Building Measurement Process as they Relate to Steps in the Existing Building Commissioning Process

These phases relate to the procedures in this Guide as follows.

Planning Phase: This phase is meant to help owners establish the goals, objectives, and execution strategy of an EBCx program to be implemented across a portfolio of buildings. This phase concludes with the completion of the EBCx Program Plan, which helps the owner decide which facility to assess first (or next). Development of the EBCx goals and facility requirements are supported by, and should be coordinated with, the evaluation, measurement and improvement plan process described in this Guide.

Assessment Phase: Development of the EBCx goals, CFRs, and a Cx plan for a single building are supported by, and should be coordinated with, the evaluation, measurement and improvement plan process described in this Guide. Some of the Basic Evaluation procedures of this Guide may be applicable to the preliminary benchmarking, occupant and operator interviews, and building walk-through tasks of this phase.

Investigation Phase: In conducting this phase, the Cx team should coordinate the development of field inspections, data gathering, testing, and analysis primarily with the Basic Evaluation process documented in this Guide but also with the Diagnostic Measurement and Advanced Analysis procedures, as appropriate. Documentation review, data collection and site surveys through a comprehensive building walk-through, occupant surveys, and systems diagnostic testing to confirm that the owner's operational requirements are met, as set forth in the CFR, are all supported by the Basic Evaluation procedures of this Guide.

Implementation Phase: Here systems, assemblies, and equipment are installed, inspected, tested, adjusted, and/or placed into service to implement the corrective actions. Elements of the OPR or CFR relating to this phase include

- developing detailed test procedures and data forms and
- verifying that systems and assemblies comply with the OPR or CFR.

The Cx team will provide step-by-step instructions to exercise systems and assemblies under test and a list of instrumentation, tools, and supplies required for each test. The team also will develop component, system/assembly, and intersystem test procedures under the full range of operating conditions (control, loads, and modes during morning occupancy, peak cooling, peak wet-bulb, and late afternoon conditions). While these tests are to provide for acceptance testing of the installation and operation of specific systems and equipment, the procedures in this Guide address overall performance of systems and the building as a whole under occupied conditions.

Some of the measurement procedures of the Diagnostic Measurement and Advanced Analysis levels may be applicable to Implementation Phase Cx. For example, Annex U of Guideline 1.1 (ASHRAE 2007a) provides a sample test procedure for comfort conditions specified in the CFRs, including a sample issues/resolution log. The occupant surveys discussed in the Basic Evaluation procedures of this Guide apply directly to such testing.

Hand-Off and Ongoing Commissioning Phases: These phases begin at substantial completion of the retrofits or renovations and continue through the end of the contractual warranty/correction period (at least through the first year of occupancy) and ideally through the life of the facility. The Ongoing Commissioning Plan (OCx Plan) is developed, the systems manual is updated, and the key deliverables are provided to the owner. The ongoing operation, maintenance, and modification of the building and its assemblies and systems are verified against the CFRs. The O&M team should follow the tasks and equipment replacement criteria set forth in Section 6 of ANSI/ASHRAE/IES Standard 100, *Energy Efficiency in Existing Buildings* (ASHRAE 2006).

If the operation of the building changes over time, new "acceptable performance" values are established and verified. While Standard 100 sets forth energy management planning, O&M, energy auditing, energy use targets, and implementation and verification requirements for existing building energy retrofits, this Guide provides detailed, step-by-step processes, at three levels of intensity, for measuring and improving building performance, not just for energy but for water and IEQ as well. Since this Guide is not a standard its processes are highly recommended but not mandatory.

Ongoing Cx is the focus of the performance measurement procedures of this Guide. Pertinent elements of the CFRs during this phase include the following:

- Providing ongoing guidance and documentation on O&M to achieve the CFRs, including facilitating ongoing optimization of the HVAC&R systems, facilitating update of the HVAC&R system preventive maintenance schedules with suitable measurement and verification documentation (ASHRAE/ACCA Standard 180 [ASHRAE 2008a] should be followed in this task), and facilitating transition to an ongoing Cx process.
- Completing seasonal testing of the building's systems and assemblies during the peak heating and cooling seasons as well as during intermediate seasons.

Responsibilities of the ongoing Cx team include verifying seasonal testing to ensure that systems and assemblies meet the CFRs and conducting and verifying periodic performance evaluations of systems and assemblies. Such periodic verification of system and component condition, operation, and performance is best done in the context of ongoing Cx. This includes periodic evaluation of achieving the CFRs against previous benchmarks. All three performance evaluation levels in this Guide address these ongoing verification activities.

DIFFERENTIATING LEVELS OF PERFORMANCE

ACCURACY, COST, AND RESOURCE REQUIREMENTS

Since commercial buildings come in all sizes, shapes, functions, and budgets and performance issues range from simple to complex, this Guide provides three levels of building performance evaluation:

- Basic Evaluation
- Diagnostic Measurement
- Advanced Analysis

These provide alternatives for building owners depending on the size, complexity, and need for their buildings.

These levels correspond to the detail, rigor, and accuracy of the measurements required to meet the performance objectives of each level. These range from whole-building measurements on an annual basis to those characterizing system, subsystem, or component performance on a monthly, daily, or hourly basis, where spatial resolution is necessary or desired. Tied closely to the measurement detail/accuracy is the cost to obtain that performance data, not only for the instrumentation but also for the personnel and time required to acquire and analyze the data.

The three levels are correlated with the portion of the building stock that would be expected to require that level of detail. Evaluators for all buildings are expected to gather and process performance data at the Basic Evaluation level. Measurements at the Diagnostic Measurement level are required of the portion of the building stock in which the building owner or operator desires a more comprehensive and thorough performance evaluation to improve performance, such as might be required to achieve a particular building rating. The Advanced Analysis level applies only to a small portion of buildings in which detailed performance measures are needed to identify building system, subsystem, or equipment performance or to diagnose a problem that has been discovered.

BASIC EVALUATION LEVEL (INDICATIVE)

The Basic Evaluation level is for the owner asking any of the following questions:

- What are my utility costs and other costs of operating my building, and how can they be reduced?
- How can my building's performance be improved?
- How does my building's performance stack up against other buildings?
- How is my building performing this year versus last year or in previous years?
- How is my building performing this month versus the same month a year ago?

This Basic Evaluation should be the first step for all buildings. It documents basic building data and measures performance using monthly utility data. The utility data allows comparison of performance versus statistical data for other similar buildings. It also allows comparisons of a building's performance from month to month or year to year. At the Basic Evaluation level the needs are fairly simple, involving operator or occupant surveys or basic instrumentation applied to the building as a whole, usually for an annual time period.

In addition to utility bill comparisons, the Basic Evaluation includes simple walk-through observations, which may identify easy-to-execute low-cost/no-cost measures to improve performance. Simple walk-through checklists, site observations, and occupant surveys are used to document current conditions as listed in Appendix A. Therefore, the Basic Evaluation data gathering and walk-through procedures presented in *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b) are applicable.

Basic Evaluation can be used by nontechnical personnel with little or no outside assistance. They can gather the data, summarize it in a report, and compare their building's performance against its own past usage or against other similar buildings' performance.

DIAGNOSTIC MEASUREMENT LEVEL (DIAGNOSTIC)

The Diagnostic Measurement level builds on the results of the Basic Evaluation level and is to be used when performance improvement beyond the Basic Evaluation level is desired. This effort is for the owner asking any of the following questions:

- When is my building consuming utilities and for what?
- Does the data indicate something is wrong or unusual in my building's operation?
- Have consumption patterns changed and if so, why?
- How do I account for variations in weather and occupancy so I'm making an appropriate comparison?

The Diagnostic Measurement level involves collecting more detailed building meter data and normalizing it to allow more accurate comparisons. The detailed data may be available electronically from the utility company if their building meter records at hourly or shorter intervals, or it may be obtained using an interval data meter, which may or may not be connected to a building automation system (BAS) (sometimes called a *building management system* or an *energy monitoring and control system*). At this level, more sophisticated instrumentation is required to track performance more frequently (monthly or weekly) or with greater spatial resolution (e.g., by individual zone). Since weather and occupancy affect utility use, adjustments to account for these effects are made at this level. It is recommended that use be separated into component use types so the effect of any changes or improvements can more readily be observed. For example, electrical use loads should be separately metered for HVAC, lighting, and plug loads.

Diagnostic Measurement is primarily intended for buildings with complex or moderately complex HVAC, lighting, or control systems. The Diagnostic Measurement level tools in this Guide include worksheets, testing and instrument recommendations, and occupant survey documents to assist in building performance improvement. Level II and Level III audit procedures for identifying and evaluating potential energy efficiency measures that are presented in *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b) may be useful here.

Measurements taken at the Diagnostic Measurement level are intended for use by technically knowledgeable owner personnel or outside consultants. Basic understanding of building systems and energy use is needed to compile gathered data, normalize it, and recognize anomalies or unusual patterns in the data. More in-depth surveys are used to document operating conditions and diagnose performance data.

When choosing outside consultants to conduct Diagnostic Measurement data collection (or Advanced Analysis investigations), the building owner should ensure that the selected consultant team has knowledge and experience in the categories listed in Table 1-1. It is improbable that any one individual will have expertise in all of these categories, so it is intended that interested firms will build teams of qualified individuals to provide the desired services.

ADVANCED ANALYSIS LEVEL (INVESTIGATIVE)

The Advanced Analysis level is for the owner asking any of the following quesions:

- I've got to cut utility costs and improve the acoustics in the building—where can I invest capital to get the most bang for my buck?
- The building's utility usage is rising—what's causing it? Is it driven by peak demand or by total energy or water use?
- The building's tenants object to the temperature control options—are these objections justified? If so, what can be done about this?
- How can I improve my building's performance to peak operating condition?
- I know I need outside help; what scope should I use in seeking that assistance?

The Advanced Analysis level builds on results from the Basic Evaluation and Diagnostic Measurement levels to address specific system deficiencies and involves much more in-depth measurement and analysis. This work requires advanced design and remediation that typically cannot be achieved by building operators, maintenance staff, or repair technicians and therefore normally is done by outside consultants. The goal is to produce detailed performance data and analysis in support of the fine-tuning of existing systems and recommendations for capital improvements. Detailed spot metering of equipment or systems, equipment performance testing, retrocommissioning, and energy modeling are tools that may be employed.

Table 1-1 Qualifications for Performing Performance Measurements

	Qualification	Basic Measurement			Diagnostic Testing			Advanced Analysis		
		Outside Consultant	Technically Knowledgable	Building Personnel	Outside Consultant	Technically Knowledgable	Building Personnel	Outside Consultant	Technically Knowledgable	Building Personnel
HVAC Systems	Knowledge of design and of how building HVAC systems function			■		■		■		
	Knowledge of test and balance procedures			■		■			■	
	Knowledge of how control systems function and of programming			■		■			■	
	Knowledge of and experience in testing control systems			■		■		■		
	Knowledge of and experience in performing energy audits			■		■		■		
	Knowledge of and experience in HVAC systems operations		■				■		■	
Plumbing Systems	Knowledge of design and of how plumbing systems function			■		■		■		
	Knowledge of plumbing hot-water systems			■		■		■		
	Knowledge of low-water-using fixtures			■		■			■	
	Knowledge of landscape watering systems			■		■		■		
	Knowledge of and experience in testing plumbing systems			■		■			■	
	Knowledge of and experience in performing water use audits			■		■			■	
	Knowledge of and experience in plumbing systems operations		■				■			■
IEQ Comfort	Knowledge of what provides space comfort			■		■		■		
	Knowledge of and experience in taking occupant surveys*			■		■			■	
	Knowledge of and experience in taking space comfort measurements			■		■		■		
	Knowledge of and experience in correcting space comfort issues			■		■		■		
IEQ IAQ	Knowledge of what provides poor IAQ			■		■		■		
	Knowledge of and experience in taking occupant surveys*			■		■			■	
	Knowledge of test and balance procedures			■		■			■	
	Knowledge of and experience in taking IAQ measurements			■		■		■		
	Knowledge of and experience in correcting IAQ issues			■		■		■		
IEQ Lighting/Daylighting	Knowledge of lighting system design and how the systems function			■		■		■		
	Knowledge of and experience in taking occupant surveys*			■		■			■	
	Knowledge of and experience in taking lighting/daylighting measurements			■		■		■		
	Knowledge of and experience in providing lighting/daylighting quality studies			■			■	■		
	Knowledge of and experience in providing lighting/daylighting retrofits			■			■	■		
	Knowledge of and experience in testing lighting/daylighting control systems			■		■		■		
IEQ Acoustics	Knowledge of acoustic system design and sound control			■		■		■		
	Knowledge of and experience in taking occupant surveys*			■		■			■	
	Knowledge of and experience in taking acoustic measurements			■		■		■		
	Knowledge of and experience in providing acoustic studies			■			■	■		
	Knowledge of and experience in providing acoustic remediation			■			■	■		

* Many organizations have limitations on collecting data on human subjects. Any occupant survey administered should abide by the organization's rules in this area.

Advanced Analysis is primarily intended for buildings with complex systems and includes recommended work processes that a consultant should perform to identify, investigate, and solve problems that can be remedied. Level II and Level III audit procedures for identifying and evaluating potential energy efficiency measures that are presented in *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b) may also be useful here.

At the Advanced Analysis level, performance may be tracked on a daily or hourly basis and at greater spatial resolution (e.g., at individual workstations and/or tracking gradients of measured values). Costs for Advanced Analysis performance measurement can range from $10,000 to upwards of $100,000 per building.

When choosing outside consultants to conduct Advanced Analysis investigations, the building owner should ensure that the selected consultant team has knowledge and experience in the categories listed in Table 1-1. It is improbable that any one individual will have expertise in all of these categories, so it is intended that interested firms will build teams of qualified individuals to provide the desired services.

WHAT'S AHEAD IN THIS GUIDE

In each of the following chapters, the protocols for each measure category (energy use, water use, thermal comfort, IAQ, lighting/daylighting, and acoustics) are presented at the three levels of Basic Evaluation, Diagnostic Measurement, and Advanced Analysis. Each section follows the format of

- objective of the performance measurement,
- measurement methods applicable to that level,
- metrics (i.e., quantifies to be measured—by surveys or physical measurements), and
- evaluation methods for analysis and benchmarking of the performance (this includes a discussion of the expected cost to obtain the measured data).

The structure and summary of the content are illustrated in Table 1-2. Measurement and instrumentation details, specific procedures, and examples of forms, worksheets, and checklists are included in the appendices, and a list of acronyms used and a list of references cited in this Guide are included as well. The CD accompanying this Guide includes the standardized forms, worksheets, and checklists Microsoft® Excel® format to simplify, facilitate, and expedite the process.

Table 1-2 Chapter Structure

		Basic Evaluation (Chapter 2)	Diagnostic Measurement (Chapter 3)	Advanced Analysis (Chapter 4)
Energy		• Walk-through observations (Level I energy audit) • Utility bill evaluation; benchmarking • Whole-building annual and monthly	• Level II energy audit • Utility bill evaluation, normalized for weather and occupancy; benchmarking • Major end-use submetering using monthly, weekly, daily and interval data, if available	• Load submetering and hourly or interval data trend analysis using the building automation system (BAS)
Water		• Walk-through observations (Level I energy audit) • Utility bill evaluation; benchmarking • Whole-building annual and monthly	• Utility bill evaluation, normalized for occupancy; benchmarking • Analysis of sanitary, landscape, and process uses monthly and weekly	• Submeter process use, landscape use, HVAC system use, and rainwater collection and/or grey water reuse
IEQ	**Thermal Comfort**	• Occupant survey • Review of service issue logs • Walk-through observations and interviews	• Inspection of problem areas using diagnostic checklist • Observation of occupant behavior • Spot measurements of temperature, humidity, and air velocity • Time-series measurements in problem areas	• Setpoint adjustments • Local control • Solar control • HVAC system changes • Right-now surveys
	IAQ	• Occupant survey • Review of service issue logs • Walk-through observations and interviews	• Measurement of outdoor air ventilation rates • Measurement of humidity in spaces • Check of exhaust airflows and filters	• Measurement of contaminants of concern (CoCs) in problem areas • Employment of building airflow models as appropriate
	Lighting/ Daylighting	• Occupant survey • Review of service issue logs • Walk-through observations and interviews	• Lighting audit/space details worksheet • Point-by-point illuminance and luminance measurements • Benchmark comparison against Illuminating Engineering Society of North America (IES) criteria	• Review of lighting walk-through checklist • Obtainment of a lighting consultant to do Advanced Analysis and make recommendations • Conduction of additional lighting surveys
	Acoustics	• Occupant survey • Review of service issue logs • Walk-through observations and interviews	• A-weighted sound pressure level measurements • Measurement of room reverberation times • Benchmark comparison against recommended sound criteria	• Obtainment of an acoustical consultant to do Advanced Analysis and make recommendations • Measurements of background noise and additional reverberation times

2 Basic Evaluation Procedures

INTRODUCTION

This chapter presents the Basic Evaluation procedures for the following measure categories:

- Energy use
- Water use
- IEQ, which consists of:
    - Thermal comfort
    - IAQ
    - Lighting/daylighting
    - Acoustics

Each of the following sections begins with an introduction, includes a detailed discussion of the evaluation procedure, and concludes with a listing of tools and aids to assist in the process. The reader is encouraged to focus on the evaluation procedure descriptions in the sections titled "Performance Measurement Procedure," which describe the plan development and seven-step process common to each of the metric categories. While many elements of IEQ are common to the four IEQ categories of thermal comfort, IAQ, lighting/daylighting, and acoustics, procedures specific to these categories are interspersed in the general IEQ discussion in this chapter.

The process chart shown in Figure 2-1 provides an overview of the Basic Evaluation level by category. This procedure defines how to measure a building utilizing the Basic Evaluation procedure. Note that the procedure begins with the development of a plan and the collection of basic data that describe the building and its monthly utility usage (a sample Building Characteristics form to record these data is shown in see Appendix A and included in the Basic Forms Workbook on the companion CD). This is followed by separate procedures for the evaluation of energy and water use performance and for IEQ performance. Standard reports and display graphs are presented for each category, and measurement and instrumentation details, specific procedures, and examples of forms, worksheets, and checklists are provided in the appendices. The standardized forms, worksheets, and checklists are also available on an accompanying CD in Microsoft® Excel® format to simplify, facilitate, and expedite the process.

The importance of maintaining good IEQ cannot be overemphasized in providing for a productive environment for building occupants. The cost savings from improving energy and water performance are far outweighed by the cost impact

BASIC EVALUATION BEST PRACTICE PROCEDURE

Collect Basic Data

1. Complete the Basic Evaluation Performance Measurement Plan
2. Complete the Building Characteristics Form
3. Collect Utility Use and Cost Data monthly
4. Collect maintenance management summary complaint logs annually

Evaluate Energy & Water Use & Cost

5. Perform a facility walk-through and complete the walk-through checklist
   a. Complete the checklist section for Energy Use and Cost
   b. Complete the checklist section for Water Use and Cost
6. Compare utility usage data and costs to past usage data and costs using
   a. Energy spreadsheet tool
   b. Water spreadsheet tool
7. Compare Energy and Water utility use data for typical facility baselines
   a. Utilize EPA's ENERGY STAR Portfolio Manager (2010) to track building energy and water usage baselines and to compare to peer facilities
8. Analyze data and walk-through discoveries to determine what corrections to make
9. Make corrections

Conduct IEQ Analysis

10. Conduct an occupant satisfaction survey—It is recommended that the Center for the Built Environment online survey be used for assessing building environmental quality as it is a low-cost process with a sophisticated survey report that allows comparison to peer buildings for IEQ (CBE 2008)
11. Review survey analysis; compare present results to past results
12. Perform a faculty walk-through and complete the walk-through checklist
13. Correct observed issues (implement corrective actions)
14. If any issue requires measurements or additional analysis or design, perform the procedures from the Diagnostic Measurement and/or the Advanced Analysis levels of this book

Report

15. Report results to managers, operators, service providers and occupants

Figure 2-1 Basic Evaluation Best Practice Procedure Outline

that IEQ has on occupant productivity and performance. The challenge for building performance improvement is to balance visual objectives, sustainability or "green" objectives, and other environmental qualities.

Maintaining good thermal comfort and IAQ are essential to the health and well-being of occupants. Keeping the indoor environment in comfortable temperature, humidity, and radiant ranges is necessary to provide for optimal working and visiting conditions in commercial buildings. An uncomfortable thermal environment is a distraction that is to be avoided. Moreover, maintaining adequate IAQ is necessary to the health of the occupants and thus can have a significant impact on absenteeism and ineffective performance in the workplace. Inadequate ventilation and the presence of toxic chemicals and/or mold are a liability to the building owner and manager.

Lighting, including daylighting, plays a crucial role in the quality of the built environment. The right lighting can improve worker productivity, enhance the aesthetic appeal of a space, improve tenant retention, increase retail sales, facilitate

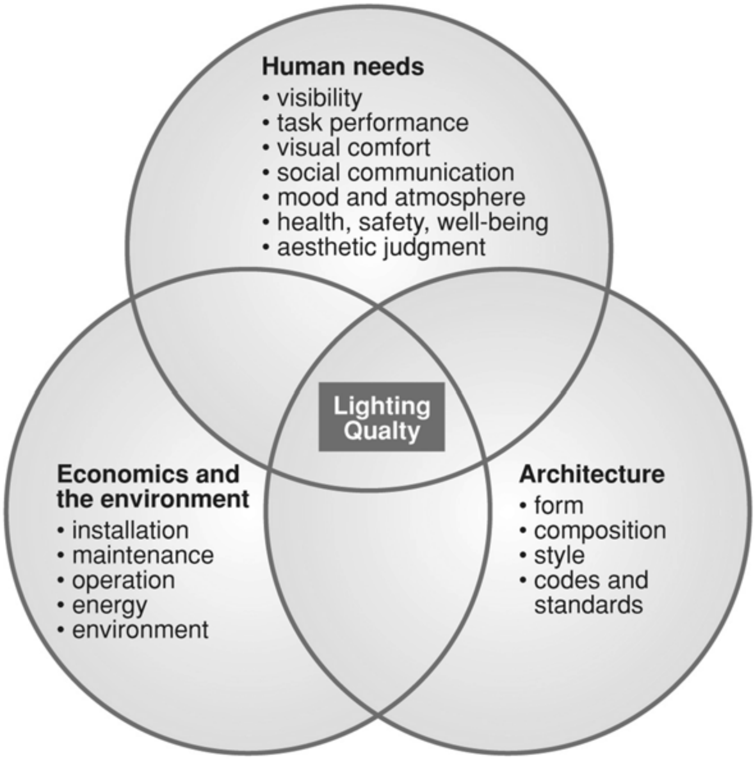


Figure 2-2 Parameters of Lighting Quality
Source: IES (2000)

education, and create the desired mood for visitors. Lighting that is poorly designed, incorrectly installed, or not properly controlled can have a costly, negative influence on each of these issues.

The issues involved in providing quality lighting are not complex but do involve more than is typically considered by the average lay person. Figure 2-2 shows the key parameters surrounding the concept of lighting quality.

Of all the IEQ factors surveyed in more than 500 buildings by the CBE (EIA 2003), the one causing the greatest occupant dissatisfaction is acoustics, including both noise level and speech privacy issues. Building acoustics is a key factor in the design and operation of any occupied space where people live and work since we need good acoustic environments to communicate for safety and productivity, to ensure that we have adequate speech privacy to protect confidential information, and to have distraction- and annoyance-free environments for healing and sleep.

Acoustic performance requirements depend on the types of activities in which occupants of these spaces are engaged. In classrooms and conference rooms, the key concern is speech communication. In office buildings, the key concerns relate to worker productivity and confidentiality of sensitive information. In medical facilities, speech communications, speech privacy, and distraction-free rest affect health-care outcomes. In hotels and motels, the key concerns relate to sleeping conditions and inter-room privacy. For some spaces a combination of the above acoustical factors will be involved.

More than anything else, the architectural and mechanical design of buildings defines the acoustical performance of the spaces within those structures. This includes room size and finishes, HVAC equipment, electrical equipment, plumbing systems, and the building envelope. Any change in acoustic performance can usually be attributed to seasonal or daily variations in the operation of the HVAC system and outside intruding noise, degradation of HVAC equipment due to poor maintenance, or building remodeling that changes the use of the space. The Basic Evaluation performance assessment is critical in defining the baseline condition of the building. Thereafter, any building redesign, interior retrofit, or control system change done to improve performance should initiate a Basic Evaluation acoustic assessment to ensure that occupant satisfaction has not been compromised.

ENERGY

INTRODUCTION

The goal in the energy category is to reduce energy consumption and cost, without compromising the comfort and well-being of the occupants, through two steps:

1. **Eliminate waste in the use of energy.** The clear advantage of energy cost reduction through elimination of such waste is that there are no service reductions and no discomfort typically associated with other energy efficiency measures (e.g., lowering thermostat setpoints). Look for low-cost/no-cost efficiency measures. This includes identification of things such as lights being on that should be off, motors running that should be off, and other devices that are needlessly on or systems that have incorrect operating schedules.
2. **Improve system and equipment operation.** A distinction needs to be made between *equipment* efficiency and efficient *system* operation. While high-efficiency components and equipment are important, the objective is efficient system operation. How do the components perform together as a system? The cost of operating the system as a whole is the bottom line. Identify power-consuming machinery that runs poorly, overheats often, uses components for which parts are no longer available, or is overdue for replacement.

Measurement at the Basic Evaluation level focuses on energy bill analysis and a walk-through inspection of the facility; no additional measurements are conducted. In addition to spreadsheet analysis of energy use from utility bills, probably the only tools needed are a pen, paper, a flashlight, and a camera. The walk-through is essentially a Level I energy audit (ASHRAE 2011b) that identifies obvious energy waste and low-cost (three years or fewer simple payback) or no-cost improvements. This level does not require an outside specialist or professional. However, issues or opportunities may be identified that require further measurement or investigation (such as that included in the Diagnostic Measurement or Advanced Analysis levels). Analysis of prospective EEMs is covered in other ASHRAE publications, such as *Energy Efficiency Guide for Existing Commercial Buildings: Technical Implementation* (2011a), *Procedures for Commercial Building Energy Audits* (2011b), and Chapter 35 of the 2011 *ASHRAE Handbook—HVAC Applications* (2011c).

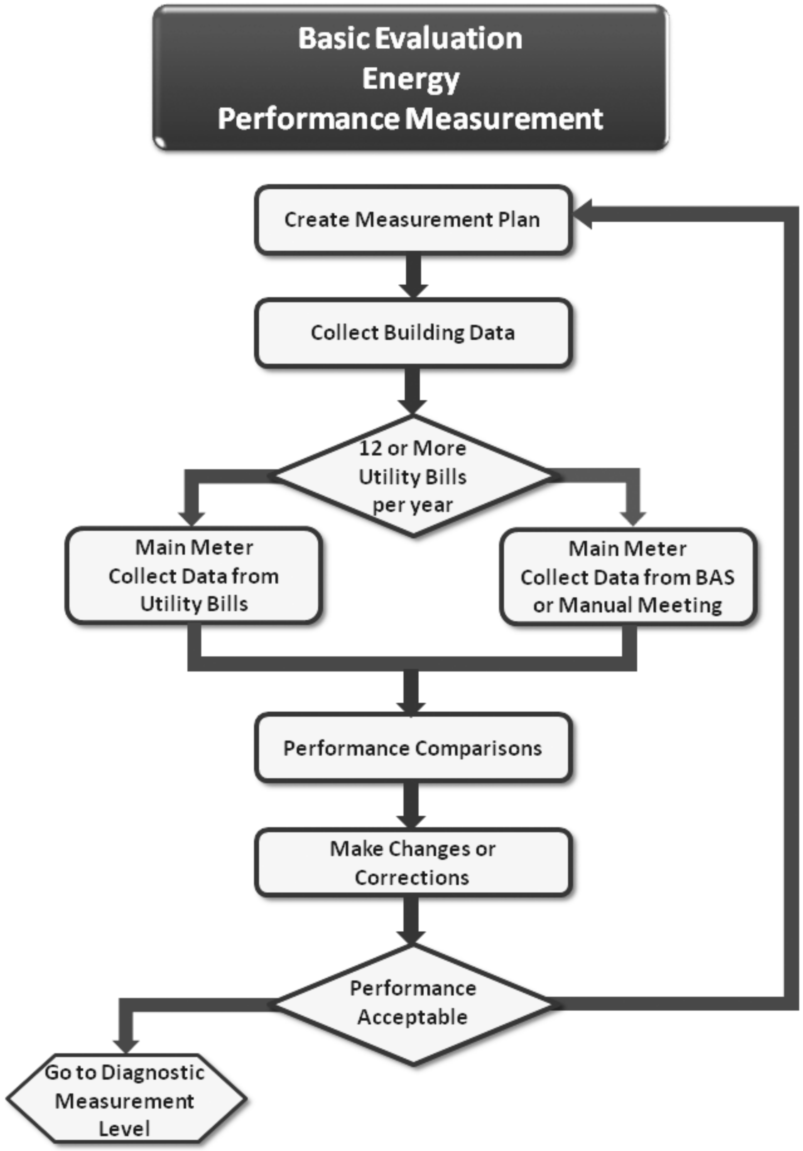


Figure 2-3 Energy Basic Evaluation Performance Measurement Procedure

PERFORMANCE MEASUREMENT PROCEDURE

The Basic Evaluation procedure uses a step-by-step process, outlined in the Figure 2-3 flowchart and in the description that follows, to inspect the facility and measure its whole-building energy use over a one-year period or shorter periods as necessary.

Develop Performance Measurement Plan

The first step in implementing the Basic Evaluation procedures is to develop a performance measurement plan, which can be quite simple and brief. Its purpose is to establish the resources needed to carry out measurements and identify the plan's expected deliverables. Building management is responsible for this step.

The person most knowledgeable about the building's day-to-day operation should be assigned to establish and implement the performance measurement plan. Use a team approach as necessary. Seek out partners, including utility providers, key tenants, key department representatives, outsourced service vendors, and other stakeholders, to develop the plan details and obtain buy-in from employees and other building users. Include stakeholder issues and opportunities. Key personnel should include any who bring intimate knowledge of their work space.

TO THE COMMISSIONING TEAM

During the planning phase of the existing building commissioning (EBCx) process, a scope of work and cost to develop the detailed plan for EBCx are prepared. This detailed EBCx plan should include development of the performance measurement plan for energy and all of the other measure categories at the Basic Evaluation level. The commissioning (Cx) team should participate in developing this performance measurement plan. The energy, water, and other goals set and the energy source benchmarks identified as part of the benchmarking process should meet those specified in the Current Project Requirements for an existing building or the OPR for a new building

The plan should be simple but thorough enough to be useful and accurate. It may include the following elements:

- Capabilities of building staff and parties/team members responsible for each part of the plan.
- Scope, with core and shell, whole building, multiple buildings, and tenant spaces separated.
- Specific energy use goal. Note that while energy targets set by standards, rating systems, or jurisdictions may be applicable, the energy goal is typically set to meet the requirements of the owner/manager.
- Energy sources to be benchmarked over a one-year period.
- Annual billing analysis, with data input in monthly increments.
- Written notice provided to occupants explaining the performance measurement plan and encouraging their active support.
- A simple checklist for the walk-through to ensure efficiency, accuracy, and thoroughness (see Appendix A and Basic Forms Workbook on the companion CD).
- The report format .
- Other elements as discussed in *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b).

It is very easy to overlook "out of sight, out of mind" system components or equipment. What are we looking for? What is a correct/incorrect condition?

Collect Building Information

A suggested table for documenting general building characteristics (Building Characteristics Form) is shown in Appendix A and included in the Basic Forms Workbook on the companion CD. The heart of Basic Evaluation measurement is benchmarking the building's energy use for at least one year.

Divide the annual energy use by the gross floor area to determine normalized energy use in kBtu/ft^2·yr (kW/m^2·yr), which is known as the energy use index (EUI). The following data are collected to accomplish this task:

- Benchmarking data
- Building description data

These types of data are discussed in more detail in the following sections.

Benchmarking Data

The following tasks should be completed to gather the benchmarking data for the Basic Evaluation level:

- Collect all energy bills.
- Collect all metered on-site energy use.
- Using Table 3-1, convert each energy component into site energy units (Btu/yr [kWh/yr]).
- Choose a 12-month period, usually corresponding to the owner's budget year period.
- If process loads are separately metered, identify process loads as distinguished from building service loads.
- Tabulate the gross floor area of the facility by usage/metered zone. For multiple-use buildings where functional spaces are separately metered, the EUI is computed separately for each such space. However, if they are not separately metered, compute the fractions of the building dedicated to various functional uses. This information is taken into account during benchmarking as an adjustment to the predominant use type (e.g., office—see Figure 3-1). If floor area is less than 10% of the predominant use, then disregard.

For most buildings, collecting this energy benchmarking data is fairly straightforward, as illustrated by the steps detailed in Table 2-1.

Table 2-1 Energy Benchmark Data Collection Steps

Step	Action	Notes and Additional Actions
Step 1	Collect metered energy use from electric and heating bills.	• If energy is used for other purposes, such as steam or chilled water, obtain any meter data for these. • Obtain related data including rate structures, electric demand, and power factor from energy bills as applicable. This energy cost data is not used for energy use benchmarking but is relevant later.
Step 1a	Collect all metered data for energy generated and used on site (if relevant).	This is to be included in the total energy use.
Step 2	Convert each energy use into site energy units (Btu/yr [kWh/yr]) using standard electricity and fuel energy conversion factors.	

Table 2-1 Energy Benchmark Data Collection Steps

Step 3	Collect process load data (if applicable).	If process loads are metered separately from building service loads, note them separately, although they should be included in the whole-building EUI. Process loads include data centers, loads in parking lots and unconditioned spaces, and industrial operations within the building, such as manufacturing processes.
Step 4	Choose a 12-month period.	This may correspond to the owner's budget year.
Step 5	Tabulate gross floor area.	Record gross floor area by usage/metered zone. Itemize core and shell 24/7 operating areas, normal weekday office occupancy areas, retail areas operating on different time schedules, and each identified process area.

TO THE COMMISSIONING TEAM

Collection of building energy data and its benchmarking should be included in the assessment and investigation phases of the EBCx process. Documentation review, site surveys taken during the building walk-through, occupant surveys, and systems diagnostic testing should confirm that the owner's performance requirements are met, as set forth in the CFR.

The walk-through checklist and report formats available in this Guide can supplement the tools used by the Cx team.

Tables 2-2 and 2-3, extracted from ANSI/ASHRAE Standard 105, *Standard Methods of Measuring, Expressing and Comparing Building Energy Performance* (ASHRAE 2007b), provide a useful format for organizing these data. The Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) website (2003) and the U.S. Environmental Protection Agency (EPA) ENERGY STAR® website (EPA 2010a) provide additional descriptive information.

At a minimum, the total energy use (item A in Table 2-5), net energy use (item B in Table 2-5), and net energy cost (item C in Table 2-5) indices should be reported, defined as follows:

$$\text{Total Energy Use Index (EUI)} = \frac{\text{Total Annual Energy Use}}{\text{Gross Floor Area}} \quad \text{kBtu/ft}^2 \cdot \text{yr} \ (\text{kWh/m}^2 \cdot \text{yr})$$

$$\text{Net Energy Use Index (Net EUI)} = \frac{\text{Net Annual Energy Use}}{\text{Gross Floor Area}} \quad \text{kBtu/ft}^2 \cdot \text{yr} \ (\text{kWh/m}^2 \cdot \text{yr})$$

$$\text{Energy Cost Index (ECI)} = \frac{\text{Net Annual Energy Cost}}{\text{Gross Floor Area}} \quad \text{\$US/ft}^2 \cdot \text{yr} \ (\text{\$US/m}^2 \cdot \text{yr})$$

Building Description Data

The following tasks should be completed to gather the building description data for the Basic Evaluation level:

- Assemble basic floor plans in readable-sized sheets showing use and utility meter zones. Document changes to the building or its systems from the time of construction that could affect system or building performance.

- Catalog systems and equipment.
- Identify all utility meters by service zone (e.g., parking lot lighting).
- Assemble maintenance records.
- Assemble service request logs.
- Assemble occupancy records.

Conduct Performance Observation, Measurement, and Analysis

Energy and Utility Bill Analysis

Sum total utility energy data in site energy units and compute annual EUI and energy cost index (ECI) based on gross floor area and data aggregated from

Table 2-2 Building Types

BUILDING TYPE* (Percentage of Gross Floor Area)	
Office	Owner Occupied
	Leased: 1-5 tenants
	Leased: 5+ tenants
	Bank/Financial
	Courthouse
	Other: ____________
Hotel/Motel	Motel (no food)
	Hotel
	Hotel/Convention
	Other: ____________
Apartment	General Occupancy
	Seniors Only
	Dorm/Fraternity/Sorority
	Other: ____________
Education	Primary
	Pre-School/Daycare
	Secondary
	College/University
	Other: ____________
Food Services	Restaurant: full service
	Fast Food
	Take Out
Health Care	Nursing Home/Assisted Living
	Psychiatric
	Clinic/Outpatient
	Active Treatment Hospital
	Other: ____________
Retail	Dry Cleaning/Laundromat
	Supermarket/Food Market
	General Merchandise
	Shopping Mall without Tenant Loads
	Shopping Mall without Tenant Lighting Loads
	Shopping Mall
	Specialty Shop
	Bakery
	Other: ____________
Assembly	Theatre
	Library
	Convention Center
	Museum/Gallery
	Church/Synagogue
	Arena/Gym
	Arena/Rink
	Nightclub
	Other: ____________

Table 2-2 Building Types

	Lounge	**Other**	Laboratory
	Other: ____________		Warehouse
			Warehouse: Refrigerated
Auto Services	Service/Repair		Recreation/Athletic Facility
	Sales		Post Office/Center
	Other: ____________		Transport Terminal
			Multi-use Complex
Public Order	Jail/Penitentiary		Other: ____________
	Fire/Police Station		

*Determine building type and then enter the percentage of gross floor area for each subarea or subtype, dividing common areas between major subareas or subtypes.
Source: ASHRAE (2007b), Form 1

Table 2-3 Total and Net Site (and/or Source) Energy Use and Net Energy Cost

Energy Type	Source of Energy Data	Energy Use Numerical Value	Units	Conversion Multiplier to kBtu (kWh)	Site Energy, kBtu/yr (kWh/yr)	Source Energy, kBtu/yr (kWh/yr) (optional)	Energy Cost $
1. Electricity—Purchased							
2. Natural gas							
3. Steam							
4. Hot water							
5. Chilled water							
6. Oil # _____							
7. Propane							
8. Coal							
9. Thermal—on-site renewable							
10. Other							
11. Electricity—on-site generated							
12. Thermal or electricity—Exported							
Total Energy—Sum of 1 to 10, plus any renewable energy from solar or wind in item 11, minus 12					**A:**	**A:**	
Net Energy—Sum of 1 to 8, plus 10, minus 12					**B:**	**B:**	**C:**

Source: ASHRAE (2007b)

monthly utility bills. Monthly subtotals provide an additional level of detail and should be adjusted to standard days/month but not normalized for weather, normal occupancy, or non-office internal loads (this is done at the Diagnostic Measurement level). All the data collected should be as accurate as practicable. Since the Basic Evaluation is intended to look at the bigger picture, a small amount of missing data (up to about 10%) is acceptable. If utility data is incomplete, manual readings or readings from the BAS may be used. Using reasonable assumptions to estimate data is valid only if a short period is missing. Graphical summary presentations on a monthly or yearly basis are very useful for understanding data trends. These are illustrated in Appendix D, and blank forms for collecting and analyzing utility data are included on the companion CD.

Beyond computing the building gross EUI and ECI, further analysis of non-office spaces may be accomplished in Basic Evaluation, but only if space-level area data is readily available. Otherwise, this data should be held for more in-depth analysis at the Diagnostic Measurement level. Also compute Electric Load Factor for each month and the highest and lowest kW demand/gross floor area during the year. The max-min demand difference may enable a quick check on the percent chiller loading.

Building Walk-Through Observations

Conduct a basic building walk-through to observe obvious energy waste, such as things being on that should be off. Large open-space facilities up to 100,000 ft^2 (9290 m^2) can reasonably be surveyed in one day; in multi-tenant spaces, it may take one day to survey up to 50,000 ft^2 (4645 m^2). If time permits, conduct additional walk-throughs during off hours to determine operation of equipment when the building is unoccupied and when only cleaning staff is present. A good practice is to use a clipboard with small-scale floor plans and a predesigned checklist; take the tour and stay on time with each prescheduled visit. Focus on taking notes but question occupants as needed to gain insights and context. Ask permission before taking pictures. Note good things as well as bad. If floor plans are available, note errors in these plans and checklist items that need adjustment. Note unusual conditions such as gross vacancies, damp or very hot/cold spaces, and overlighted spaces. Save using a light meter or hand-held temperature meter until the Diagnostic Measurement evaluation. Detailed checklists with recommended corrective actions (Walk-Through Checklists and Recommended Corrective Actions) to facilitate the walk-through process are shown in Appendix A and included in the Basic Forms Workbook on the companion CD.

Include mechanical systems in the walk-through. Determine the operating schedules of equipment, both by interviewing staff and by verification of time clock settings and/or BAS settings. Verify that operating schedules conform to building occupancy. Determine if ventilation dampers open when air-handling units are energized or if they delay opening until the building is occupied. Determine if exhaust fan operation conforms to building occupancy, where pertinent.

Interview building occupants, users, technicians, and external support staff. Note that in the IEQ Basic Evaluation sections, occupant surveys are recommended that will provide some of this occupant feedback.[i] Review service request records, observations, and suggestions for energy use optimization. Pay particular

i. Note that many organizations have limitations on collecting data on human subjects. Any occupant survey administered should abide by the organization's rules in this area.

attention to areas where complaints or negative observations have previously been reported. Note any Diagnostic Measurement actions needed. Note that occupant interviews should be clearly voluntary and informal, with responses carefully protected and anonymous to minimize the potential for violation of privacy, jeopardizing of employees' jobs, and other abuses.

Conduct Performance Comparison (Benchmarking)

If the building has been benchmarked within the last three years, analyze it compared to both its own past performance and to a recognized baseline database, per the items in the sections that follow.

To Past Performance

Compare the building to its past performance in both EUI and ECI, but focus on EUI to search for improvements. Annual whole-building data for previous years can be obtained from utility bills and analyzed using a simple spreadsheet.

TO THE COMMISSIONING TEAM

During the investigation phase of the EBCx process the Cx team should conduct the annual energy utility bill analysis as well as the comparison to appropriate benchmarks, as discussed in this Basic Evaluation section. This early evaluation will provide the basis for subsequent energy improvement efforts. If the energy evaluation of the first occupied year is conducted as part of the initial Cx process for a new building, this will serve to verify indirectly the seasonal testing and adjustment of the building's systems and assemblies during the peak heating and cooling seasons as well as during intermediate seasons. This evaluation provides additional tools for use during the implementation, hand-off, and ongoing Cx phases of EBCx.

Benchmark monthly data is used to look for seasonal differences and gradual increases in use over time. Answer these questions:

- Has your energy use increased compared to last year?
- Has peak demand increased?
- Has energy cost increased?
- What might be the cause of these variations (weather, occupancy, equipment changes, change in use, utility rates, etc.)?
- Review the walk-through energy survey for likely causes of differences from past years. Any change in use of 10% or more is a candidate for further Diagnostic Measurement study.

To Baseline Databases

Compare the building with peer buildings in existing databases, such as EPA's ENERGY STAR Portfolio Manager (2010b) (note that this is normalized for weather, occupied hours, internal loads, and geographic location) or the Building Owners and Managers Association (BOMA) International Experience Exchange Report® (2012), or with other facilities in your portfolio or campus. In some locales there may be energy use database information from the local utility or state energy office. As in the past performance comparison, if the building is less than the 75th percentile of other similar buildings, it is a candidate for further Diagnostic Measurement study.

Another source of baseline data is the CBECS (EIA 2003). Table 2-4, adapted from the 2011 *ASHRAE Handbook—HVAC Applications* (2011c), lists EUI distributions for CBECS data for buildings surveyed in 2003.

If the building EUI compares poorly to the comparative database values, a more thorough examination (using the Diagnostic Measurement or Advanced Analysis methods suggested in this Guide) of the building's systems and operations should be initiated to discover the reasons for the poor performance.

Identify Issues Needing Correction and Take Corrective Actions

Use the Basic Evaluation walk-through survey as a basis for making adjustments as follows:

- Adjust space area and use calculations for changes in floor area observed in the walk-through as compared to those presented in the benchmark exercise.

Table 2-4 Commercial Sector Floor Area and EUI Percentile

Building Use	Calculated, Weighted		Actual Number of Buildings, *N*	Calculated, Weighted Energy Use Index (EUI) Values Site Energy, kBtu/yr per gross square foot					
	Number of Buildings, Hundreds	Floor Area, 10^9 ft^2		Percentiles 10th	25th	50th	75th	90th	Mean
Administrative/professional office	442	6.63	555	28.1	41	62	93	138	75
Bank/other financial	104	1.10	75	55.7	67	87	117	184	106
Clinic/other outpatient health	66	0.75	100	28.7	41	66	97	175	84
College/university	34	1.42	88	14.1	67	108	178	215	122
Convenience store	57	0.16	28	68.6	156	232	352	415	274
Convenience store with gas station	72	0.28	32	82.2	135	211	278	409	225
Distribution/shipping center	155	5.25	231	8.7	17	33	54	91	45
Dormitory/fraternity/sorority	16	0.51	37	36.3	65	74	100	154	90
Elementary/middle school	177	4.75	331	21.1	35	54	93	127	76
Entertainment/culture	27	0.50	50	1.7	29	46	134	418	95
Fast food	78	0.26	95	176.3	268	418	816	933	534
Fire station/police station	53	0.38	47	6.9	24	82	112	137	78
Government office	84	1.55	150	31.5	52	77	103	149	85
Grocery store/food market	86	0.71	117	98.1	138	185	239	437	213
High school	68	2.52	126	19.8	44	65	99	130	75
Hospital/inpatient health	8	1.90	217	108.1	169	196	279	355	227
Hotel	20	1.90	86	39.7	51	73	116	183	95

Table 2-4 Commercial Sector Floor Area and EUI Percentile *(continued)*

Building Use	Calculated, Weighted: Number of Buildings, Hundreds	Calculated, Weighted: Floor Area, 10^9 ft^2	Actual Number of Buildings, *N*	Calculated, Weighted Energy Use Index (EUI) Values Site Energy, kBtu/yr per gross square foot: Percentiles 10th	25th	50th	75th	90th	Mean
Laboratory	9	0.65	43	98.0	165	270	505	925	362
Library	20	0.56	36	35.0	67	92	121	197	104
Medical office (diagnostic)	54	0.50	58	14.1	25	44	100	137	60
Medical office (nondiagnostic)	37	0.22	33	25.7	40	52	66	109	59
Mixed-use office	84	2.30	172	20.0	38	71	106	158	88
Motel or inn	70	1.05	109	23.9	37	67	102	197	87
Nonrefrigerated warehouse	229	3.05	172	2.3	6	19	46	87	34
Nursing home/assisted living	22	0.98	73	41.6	77	116	184	205	124
Other	70	1.08	68	5.5	29	69	96	118	74
Other classroom education	51	0.71	60	4.3	23	40	64	108	51
Other food sales	10	0.10	10	31.5	37	58	190	343	126
Other food service	58	0.33	56	39.6	71	125	309	548	242
Other lodging	16	0.65	28	31.2	54	71	83	146	76
Other office	73	0.41	52	15.3	41	57	84	146	69
Other public assembly	32	0.42	31	9.9	30	42	73	155	65
Other public order and safety	17	0.71	38	44.0	58	93	160	308	127
Other retail	47	0.24	42	32.7	65	92	146	205	120
Other service	139	0.48	171	28.0	50	86	164	303	168
Post office/postal center	19	0.50	23	7.2	58	64	76	97	64
Preschool/daycare	56	0.48	46	18.8	35	59	112	121	75
Recreation	96	1.28	99	13.4	24	40	88	152	68
Refrigerated warehouse	15	0.53	20	6.5	13	143	190	257	127
Religious worship	370	3.75	313	9.3	17	33	63	88	46
Repair shop	76	0.65	51	7.0	13	30	54	72	37
Restaurant/cafeteria	161	1.06	212	51.8	117	207	462	635	302
Retail store	347	3.48	460	14.2	25	45	93	170	72
Self-storage	198	1.26	84	2.1	4	7	10	15	9
Social/meeting	101	1.18	78	7.9	15	41	71	93	52
Vacant	182	2.57	178	1.4	3	12	31	77	26
Vehicle dealership/ showroom	50	0.60	40	24.5	40	82	110	248	110
Vehicle service/repair shop	212	1.21	131	10.1	16	37	86	137	58

Table 2-4 Commercial Sector Floor Area and EUI Percentile *(continued)*

Building Use	Calculated, Weighted		Actual Number of Buildings, *N*	Calculated, Weighted Energy Use Index (EUI) Values Site Energy, kBtu/yr per gross square foot					
	Number of Buildings, Hundreds	Floor Area, 10^9 ft^2		Percentiles					Mean
				10th	25th	50th	75th	90th	
Vehicle storage/maintenance	176	1.21	99	0.9	4	21	53	152	54
SUM or Mean for sector	4645	64.78	5451	9.8	26	56	108	207	97

Source: Adapted from *ASHRAE Handbook—HVAC Applications*, Chapter 36, Table 2 (2011c). Calculated based on DOE/EIA preliminary 2003 CBECS microdata.

TO THE COMMISSIONING TEAM

During the implementation phase of the EBCx process the Cx team reviews and monitors the corrections and adjustments for improving the energy performance that were identified during the Basic Evaluation. Monitoring of test and balance activities is included. The team will also monitor the remeasurement of performance and the comparison of new performance results to past performance results. The measurement and verification tasks are included in this performance measurement and remeasurement and are executed in the implementation phase completion activities.

- Review the survey to target and implement no-cost and low-cost EEMs noted in the survey.
- Note spaces that should be candidates for submetering and weekly or daily monitoring during a Diagnostic Measurement study.
- Refer to the checklist of potential energy efficiency measures (see Appendix A). EEM delivery may be completed by in-house staff, an energy management contractor, a design-build firm, or an energy performance contractor.

Remeasure Performance

Refine the performance measurement plan and its implementation team. Conduct a “lessons learned” meeting to identify and assign changes to data collection procedures, walk-through procedures, and comparison analyses. If space area or use data were in error, it may be worthwhile to recalculate the building EUI and the ECI.

Compare New Performance to Past Performance

Is performance acceptable? Did the results meet your goals? If not, use the procedure described for the Diagnostic Measurement level and conduct energy team evaluation of expectations—why didn’t things work, whether expectations were met or not met. If performance is acceptable, repeat the process next year but continue to monitor energy patterns monthly. The new performance should also be compared to the appropriate benchmarks.

Report Results

Once information is acquired and initial conclusions have been derived, preliminary reporting to key people may result in useful input. Subsequently, a final action plan should be developed and implemented with periodic review for appropriate adjustments and addressing issues where expectations have not been reached. Observations and the action plan should be the base documents for the next inspection. Special attention should be paid to recurrent issues.

No matter what the outcome of the Basic Evaluation study, it is important to produce a brief management report of the task that includes the following elements:

- Executive summary
- Summary of the performance measurement plan
- Summary of the walk-through findings
- Summary of the benchmarking results in graphical form and a brief discussion of findings
- Statement of the next action commitments for energy savings, including specific achievable targets

TO THE COMMISSIONING TEAM

During the hand-off and ongoing Cx phases of the EBCx process, the Cx team conducts the full range of functional testing to ensure that the commissioned systems perform in accordance with the CFR.

TO THE COMMISSIONING TEAM

The review of the Basic Evaluation performance measurement process and its results should be documented by the Cx team. The results will be reported to the building owner and manager and their consultants as an initial part of the hand-off and ongoing Cx phases of the EBCx process. This will include an action plan for the implementation and periodic review of operating parameters and their continuing adjustment, as well as retrofit as necessary, as part of a continuous maintenance and operations plan. The persistence of performance improvement will only be accomplished through this continuing action.

TOOLS AND AIDS

Only simple tools should be needed to perform a basic benchmarking exercise. They would likely consist of monthly energy bills and scaled floor plans of the building. If as-built mechanical drawings are available, they are a great resource to identify HVAC equipment locations. Similarly, architectural reflected ceiling plans and lighting schedules are useful for identifying lighting fixture types and wattages.

When conducting the building walk-through, again, keep it simple. Use a clipboard, small-scale floor plans, the prepared checklist, a flashlight, a note pad, a pen, and a camera.

Review the companion CD and appendices for more help, including the following:

- Spreadsheets and sample graphics (Appendix D)
- Sample walk-through inspection checklist (Appendix A)
- Level I Energy Audit processes and procedures references
    - ASHRAE Standard 105 (2007b)
    - *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b)
    - *Best Practices in Commissioning Existing Buildings* (BCA 2008)
    - *Technical Retro-Commissioning Process/Procedures* (NEBB 2007)
    - *Procedural Standards for Building Envelope Testing* (NEBB 2012)
    - *ACG Commissioning Guideline and Appendix D* (ACG 2005)
    - NIBS Guideline 3, *Building Enclosure Commissioning Process* (NIBS 2008a)
    - Whole Building Design Guide, www.wbdg.org (NIBS 2012)

WATER

INTRODUCTION

At the Basic Evaluation level, lower water use is achieved by the following methods:

- The first and most important method is to eliminate water leaks or wasted usage. This is done by eliminating any water pipe leaks, leaking plumbing fixtures, and leaking landscape watering systems.
- The second method is to improve the water use efficiency of existing plumbing fixtures by upgrading the fixtures or adding water restrictors and by reducing the amount of water used for landscaping.

Basic Evaluation water measurement protocols use the utility water meter as the point of the measurement to verify the performance of the system. The measurements are used to analyze whether the use is increasing or decreasing from the same month of the previous year.

PERFORMANCE MEASUREMENT PROCEDURE

The Figure 2-4 flowchart indicates the basic procedures for lowering water usage. If the facility does not have a water utility, then a water meter in the main water feed to the building can be manually read to provide the usage data. Some utilities require separate landscape water meters to establish wastewater charges. For these facilities it is recommended to use the landscape water meter readings to enhance the water savings opportunities for landscape water use. If the facility does not have a landscape meter, landscape water use data will be included in the main water meter data.

Develop Performance Measurement Plan

The performance measurement plan should include the following:

- A specific water reduction goal over time. This may be a percentage saved per year or a specific quantity saved over time.

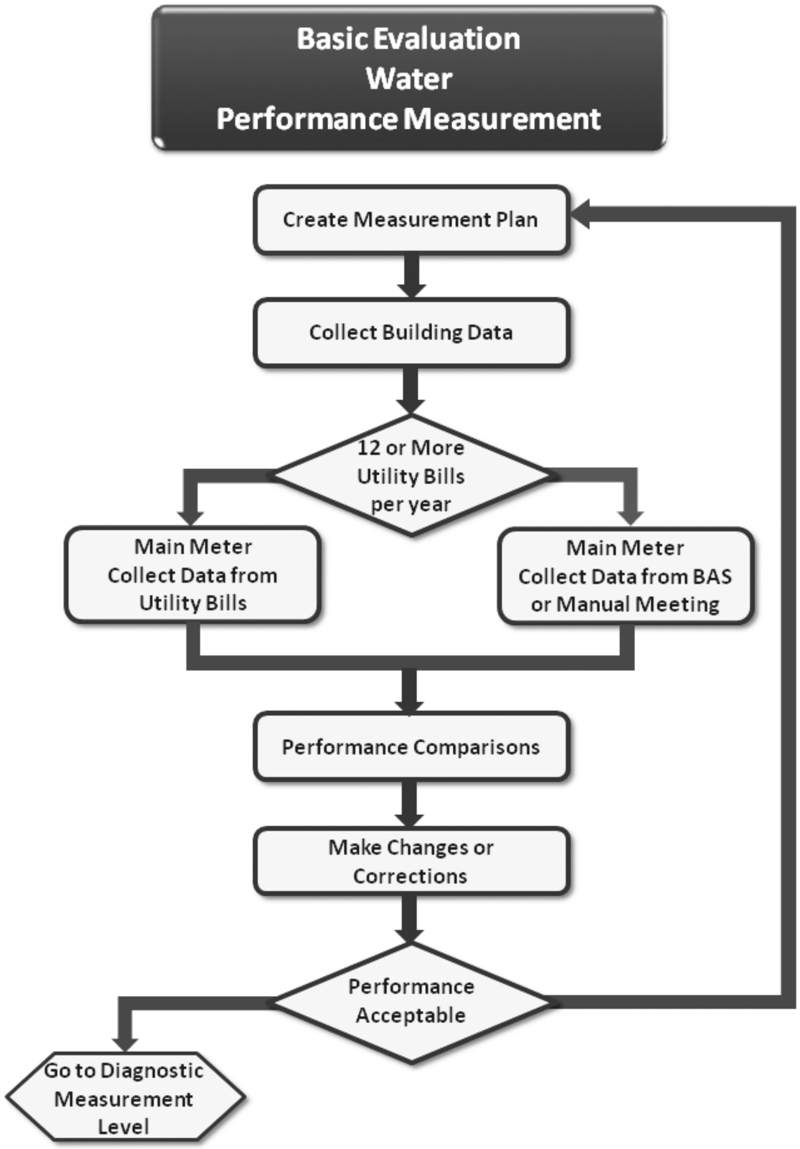


Figure 2-4 Water Basic Evaluation Performance Measurement Procedures

- A description of the end uses to be a part of the water reduction plan, such as building sanitary use, landscape water use, kitchen water use, process water use, cleaning water use, etc.
- A description of existing water meters and the meters that will be used in the performance improvement process.
- Identification of who will perform the following tasks:
  - Supervise the performance plan and processes
  - Take or accumulate the measurement data
  - Perform the data analysis and comparisons
  - Decide on the corrections or adjustments to make
  - Be responsible for making the corrections or adjustments
  - Publish the results to management, operators, and occupants

Collect Building Information

Basic information about the facility needs to be collected and recorded to use during the measurement and comparison process. The following basic information is needed:

- Total occupied square feet (square meters) of building area
- Number of floors included in the occupied area
- Total area of watered landscape
- Type of occupancy/functions conducted in the building
- Descriptions of any special water uses such as process or kitchens

Conduct Performance Observation, Measurement, and Analysis

Utility Bill Analysis

For the Basic Evaluation level, the only measurements are the utility or local water meter data. It is suggested that monthly readings are preferred to obtain more accuracy in the usage over time. This data can be obtained from monthly utility water bills or can be taken directly from the water meter automatically by the BAS or manually. If taking manual or local readings, verify the units used at the meter. Many utilities use 748 gallons per meter as the unit of measure, so verify this amount from your utility or meter manufacturer.

Input the monthly water use and cost data into the Basic Evaluation Water Verification Worksheet or other similar comparison worksheet to allow comparison of usage over time. Example graphical displays are illustrated in ~~Figure G-2 in~~ Appendix F (Basic Evaluation Workbook Chart Examples). Blank forms are included on the companion CD in the Basic Evaluation Water Verification Workbook.

Walk-Through Assessment

A walk-through of the building should be conducted to identify water use issues. Detailed checklists with recommended corrective actions to facilitate the walk-through process are shown in Appendix A and included in the Basic Forms Workbook on the companion CD.

Conduct Performance Comparison (Benchmarking)

To Past Performance

Current performance is compared to past performance through the Basic Evaluation Water Verification Worksheet, which compares the current and past months' data to the same period's data for the previous year (see example worksheet and charts in Appendix F and blank forms on the companion CD).

To Baseline Databases

Once past usage is established, use ENERGY STAR or other national databases (Table 2-3) to rate the existing facility water use compared to the water use of similar facilities. Record this rating for reference when comparing future results.

Identify Issues Needing Correction and Take Corrective Actions

Using the improvement suggestions from Appendix A or other suggestions from water reduction information sources, determine the steps that can be taken to reduce the current water use. Some typical suggestions are as follows:

- Lower the building supply water pressure to the lowest level possible that still allows the top-most fixture to operate adequately.
- Repair all leaks in lines or plumbing fixtures or faucets.
- Install low-flow fittings on existing fixtures and showers.
- Replace existing plumbing fixtures with lower-flow fixtures.
- Lower landscape water times and flows to the minimum required for the existing plantings.

Water usage is normally overlooked by most occupants and operators as unimportant. Therefore, the most important adjustment to lower water use is to keep occupants aware of the amount of water used and to keep them focused on water use reduction.

Remeasure Performance

Once corrections and adjustments have been made, remeasure the performance of water usage. This can be done by using the next utility bill or by taking manual meter readings. If taking manual readings, make sure the time duration sampling periods are the same as previous sampling periods so meaningful comparisons can be made.

Compare New Performance to Past Performance

Using the new period's measurements, compare this time period to the past year's same time period to determine whether the adjustments or corrections have made a difference in water use characteristics. Be aware that variances in the number of building occupants or schedules will change water usage in buildings due to increased/decreased usage of plumbing facilities and increased/decreased load on HVAC systems. If it is desired to normalize present usage for these variances, use

Table 2-5 Representative Water Use Indices, U.S. and Germany

User	DOE FEMP[1]		Association of German Engineers[2]	
	Goal	Units	Goal	Units
Airport	3	gal/passenger	49.2	L/passenger
Apartment House	100	gal/person/day	2.00	m^3/m^2/year
Resort Apartment	60	gal/person/day		
Boarding House	40	gal/person/day		
Hotel	50	gal/guest/day	182	liter/guest/day
Lodging House	40	gal/guest/day		
Motel	35	gal/guest/day	167	liter/guest/day
Motel with Kitchen	40	gal/guest/day		
Laundry	550	gal/machine/day		

Table 2-5 Representative Water Use Indices, U.S. and Germany

Office	15	gal/employee/day	.50	m^3/m^2/year
Court Building			.50	m^3/m^2/year
Data Center			1.00	m^3/m^2/year
Public Lavatory	5	gal/user/day		
Restaurant—Conventional	9	gal/customer/day		
Restaurant—Short Order	8	gal/customer/day		
Shopping Center	8-13	gal/parking space/day		
Bowling Alley	200	gal/alley/day		
Country Club	100	gal/member/day		
Campground	30	gal/person/day		
Swimming Pool, Beach	10	gal/customer/day		
Assembly Hall	3	gal/seat/day		
Dormitory	35	gal/person/day		
Police Station			0.40	m^3/m^2/year
Prison	120	gal/inmate/day	2.80	m^3/m^2/year
Medical Hospital	120	gal/bed/day	500	L/bed/day
School	10	gal/student/day	2074	L/student/year
School with Cafeteria	15	gal/student/day		
School Cafeteria and Gym	25	gal/student/day		
University Building			0.60	m^3/m^2/year
Landscape—Non-Turf	785	gal/acre/day		
Landscape—Turf	1571	gal/acre/day		

the procedures for water use normalization in the Diagnostic Measurement procedures discussed in this Guide.

Report Results

It is important that building operators and occupants be made aware of how successful the water reduction efforts have been over recent time periods, as the actions of building occupants and operators have a large effect on water usage. It is recommended that the output graphs of the Basic Evaluation Water Verification Worksheet be published to all building occupants and operators. These documents can be used by building owners and operators for educating and encouraging occupants to lower water use continuously and to discourage water waste.

TOOLS AND AIDS

Filled-out example forms and charts from the Basic Evaluation Water Verification Workbook tool are shown in Appendix F and included on the companion CD to assist the user in collecting and utilizing the data for analysis and to produce easily meaningful output information for publication. To use this tool, simply input each month's water use and cost data from the utility bills into the cells that correlate to the rate structure on the current utility data page. If the utility rate structure does not match the provided spreadsheet, modify the sheet accordingly without disrupting the total lines that feed the output graphs and trends. Also input the previous year's monthly data into the previous year utility data page. The data is automatically normalized for standard days in a month. This data automatically produces the water use and cost output charts, which can be used to publish the results of the water use and reduction efforts.

INDOOR ENVIRONMENTAL QUALITY (IEQ)

INTRODUCTION

At the Basic Evaluation level, recommended activities are indicative in nature, determining whether perceived IEQ is adequate or whether there are deficiencies that can be corrected without the need for physical measurements, with measurements and analysis as indicated at the Diagnostic Measurement level, or with the services of a professional with IEQ expertise as discussed at the Advanced Analysis level. Because many of these activities are common to all four IEQ categories (thermal comfort, IAQ, lighting/daylighting, and acoustics), with few exceptions, they are presented in general terms in this section, with specific reference to those aspects that are unique to each category.

This section provides nonspecialists with advice and tools for evaluating the IEQ within a building space. The Basic Evaluation level for IEQ is a two-part process that includes the following:

1. Occupant survey
    - Requesting comments from occupants regarding thermal comfort, IAQ, lighting/daylighting, and acoustics, either separately or as a group
    - Direct occupant comments captured by building operations and/or management
2. Field observations
    - Thermal comfort
        - Temperature, humidity, and air movement
        - Human activity in each space
        - Space configuration (section depth from fenestration, window/wall area, operable windows)
        - HVAC system and its operation
        - Private and open-plan areas
    - IAQ
        - Ventilation
        - Moisture management
        - HVAC system and its operation
        - Building pressurization
        - Dirt and contaminant capture
        - Contaminant sources
    - Lighting/daylighting
        - Amount of light in the work space
        - Visual comfort

    - Overall lighting quality
- Acoustics
    - Background noise in the workplace
    - Noise intrusion between spaces
    - Acoustic privacy
    - Speech communication
    - Overall acoustic quality of the work space

Environmental Factors and Their Interaction

As is described in detail in ASHRAE Guideline 10, *Interactions Affecting the Achievement of Acceptable Indoor Environments* (2011d), to provide an acceptable indoor environment it is necessary not only that each aspect of the environment be satisfactory but also that adverse impacts of the interactions among these aspects are limited. The four factors of IEQ—thermal comfort, IAQ, lighting/daylighting, and acoustics—are widely regarded as the primary categories for characterizing different aspects of the indoor environment. Each of these factors includes several separate aspects. For example, within lighting/daylighting are included luminance and illuminance, color rendering, contrast ratios, view quality, discomfort glare, etc. Therefore, the number of potential interactions is quite large.

Occupant experience of, and response to, the indoor environment may also be strongly affected by considerations not strictly considered among the four major indoor environmental factors. Although most of these considerations are subjective and difficult to quantify, they may dominate individual reactions to a space. These other considerations include, among others, the ergonomics of the work space, the time of day and season of the year, the proximity of other occupants, privacy and security, spatial qualities (volume, shape), the presence of windows and outdoor views, and freedom of movement. Users of this Guide should be aware that one or more of these factors can have significant or even dominant effects on the acceptability of the indoor environment, regardless of other factors. The factors do not necessarily have equal weight, and occupant surveys in offices have often found the quality of the interior environment to be very important to environmental satisfaction.

Satisfaction and Human Adaptability

People are not passive receptors of their environment; rather, they interact continuously with it. Given the opportunity, people will adjust to their environment and will adjust their environment to themselves. Such adjustments by building occupants can sometimes cause problems elsewhere—e.g., if occupants are experiencing glare from the daylighting, they may choose to keep the blinds closed continuously, thereby eliminating any potential energy savings that could be provided by the daylight through reduced use of electric lighting. On the other hand, problems associated with the indoor environmental factors can sometimes be circumvented by providing the occupants suitable control over their environment. They then perform their own optimization and balancing of factors as their requirements vary from time to time and task to task.

For example, the principal aspects within the thermal environment are the air temperature, thermal radiation from surrounding surfaces, and the movement of air and its moisture content, while the principal personal aspects are the thermal insulation of clothing, the degree of activity, and physiological status of the individual. Providing control for local air temperature, air movement, or thermal radiation and adequate freedom in the choice of clothing will usually ensure thermal satisfaction. Details of this adaptability are given in Section 4.3 of ASHRAE Guideline 10 (2011d) and ASHRAE Standard 55 (2010b). Similarly, providing sound-isolated conference rooms for meetings and telephone conversations can mitigate acoustic privacy concerns in open-plan offices.

The main environmental factors directly affect the human body, and their physiological effects may be perceived by the occupants. How these perceptions are interpreted will affect the acceptability of the environment. A perception can therefore modify an occupant's interpretation and consequent response, whether or not the perception is correctly attributed to its actual cause. Prior exposure and exposure time also modify the human response to the environment. For example, humans adapt to odors, perceiving them to be less intense over time. In contrast, irritants work the other way around: their effects tend to increase with extended exposure.

PERFORMANCE MEASUREMENT PROCEDURE

The procedures shown in the Figure 2-5 flowchart include items and steps specific to the evaluation of thermal comfort, IAQ, lighting/daylighting, and acoustics, respectively. These steps are not necessarily sequential but are presented in an order that will assist the user in determining whether there are IEQ issues and how to proceed if there are. A detailed discussion of each of the procedural steps follows.

Develop Performance Measurement Plan

The performance measurement plan should be developed keeping in mind that IEQ issues may include elements that can affect energy costs and/or occupant satisfaction and productivity. The plan will set the scope and the parameters of data collection and will assign responsibilities to the appropriate individuals.

The first step in the plan is setting goals. The owner/manager must first decide whether the building's IEQ performance needs examination. This decision is usually made by management, who then might delegate someone within the organization to carry out the next steps.

The second step is measurement. Performance improvement involves establishing the building's performance against existing benchmarks and by comparing subsequent performance measures with previous ones, preferably at an annual or shorter interval. Benchmark performance data can be obtained using standardized occupant surveys,[ii] either in a searchable database or as summarized data. The surveys should contain questions allowing the causes of performance problems to be identified so that remedial/improvement actions may be considered by building management.

The third step is implementation of measures to remedy issues to improve comfort, and the last step in the plan is remeasuring performance. As improvement measures are implemented, their effects on performance should become evident in subsequent surveys. Each survey's questions should be consistent with the first survey, and records should be kept of the improvement measures and other significant changes to the building between the surveys.

ii. Note that many organizations have limitations on collecting data on human subjects. Any occupant survey administered should abide by the organization's rules in this area.

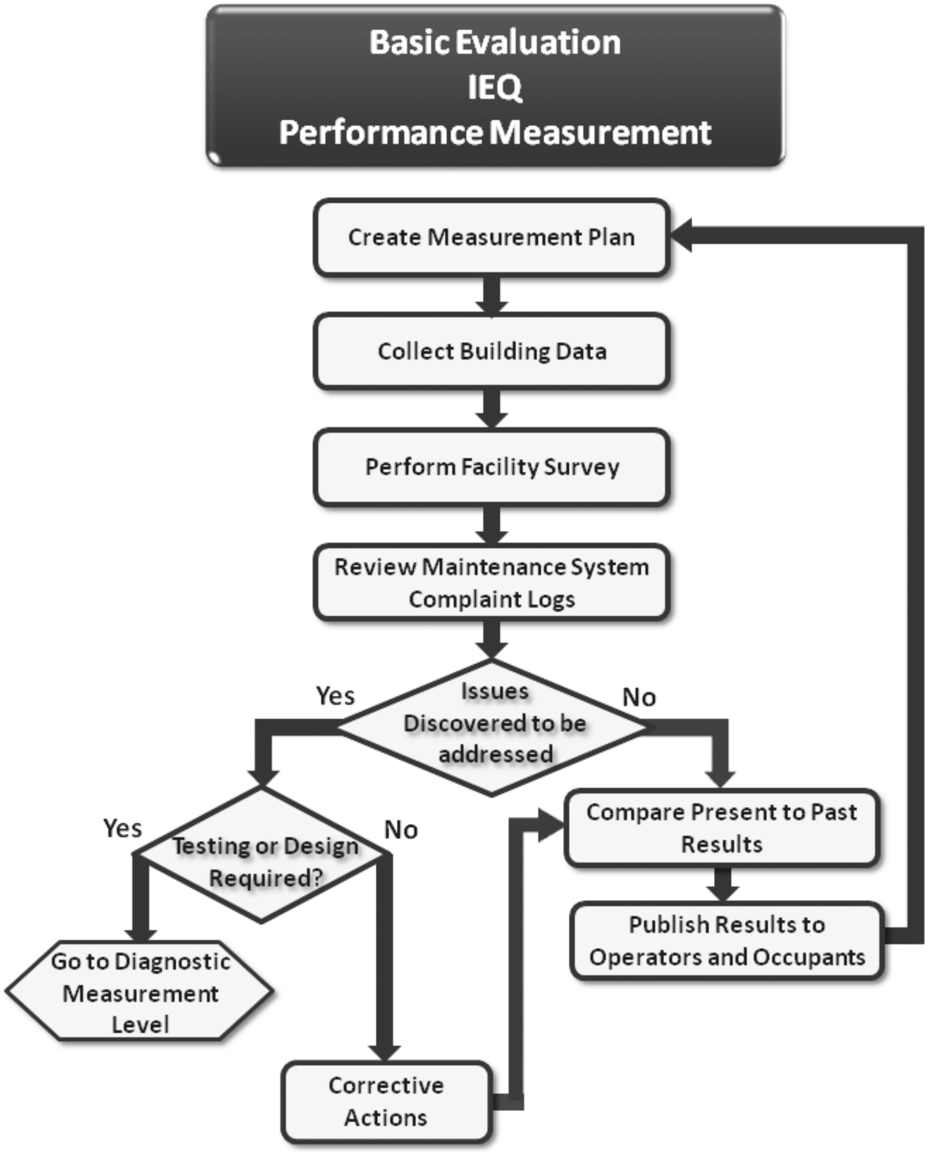


Figure 2-5 Indoor Environmental Quality Basic Evaluation Performance Measurement Procedures

The performance measurement plan should include descriptions of the following:

- The building spaces to be included in the facility walk-through and the occupant survey, as well as HVAC and lighting zones and the functions therein. For lighting, consideration should be given to including any spaces where visual acuity is important; for acoustics, consideration should be given to including any spaces where speech communication or privacy is of particular importance.
- How occupant satisfaction will be benchmarked.
- The procedure for the facility walk-through and audit of service issue logs.
- Who will perform the following tasks:

- Supervise the performance plan and processes.
- Complete the Walk-Through Checklist (Appendix A).
- Conduct the occupant survey and take or accumulate the survey data.
- Conduct the data analysis and comparisons to benchmarks and previous measurements (if available).
- Identify issues to be addressed.
- Decide on corrections to be taken, including enlisting persons with appropriate technical expertise.
- Be responsible for making the corrections or adjustments.
- Report the results to management, operators, and occupants.
- Conduct remeasurement in subsequent years.

A Basic Evaluation Measurement Plan Form for documenting these plan elements is provided in Appendix A.

Collect Building Information

Basic information about the facility needs to be collected and recorded for the Basic Evaluation level. This process can be facilitated by using the forms found in Appendix A and in the Basic Forms Workbook on the companion CD (Building Characteristics). Building maintenance logs should be reviewed to identify any IEQ issues. For inspecting the physical features of the occupied portions of the building it will be necessary to have accurate as-built drawings. A building walk-through may include the use of simple meters for temperature and perhaps humidity.

To identify the basic information needed to inspect the important physical features of the occupied portions of the building, keep the data simple. The data needed for the energy and lighting components of this performance measurement level will overlap these. For thermal comfort, the following are needed:

- List of the occupied spaces
- Human activity (room use) in each space
- Description of HVAC zones as related to building functions, including exterior and interior spaces
- Type of HVAC equipment supplying each space
- Location of rooms within the building (outside wall, floor for multistory buildings, adjacent room uses, etc.)
- Floor area (ft^2 or m^2)
- Number of floors
- Section depth from fenestration—perimeter/core; wings north, east, south and west
- Window/wall ratio (the percentage of wall area taken up by window area)
- Operable windows
- Private and open-plan areas
- General condition of structure and furnishings

For IAQ, provide building baseline information per the previous list and include the following:

- Temperature and humidity setpoints and ventilation rates for each room and/or HVAC zone (these can be obtained from the BMS or, if no BMS is present, from the as-built design documents)
- General condition of HVAC system(s)
- General state of housekeeping
- Contaminant sources in and near the building

When using the forms shown in Appendix I (Lighting/Daylighting Workbook and Resources) and included on the companion CD, the person completing the form should communicate two types of information:

1. how extensively the different generic types of lighting and lighting controls are being used within the target space(s), and
2. how recently the lighting equipment has been maintained.

For acoustics, the following are needed:

- List of the occupied spaces
- Human activity (room use) in each space
- Approximate room volume (ft^3 or m^3) and surface finishes (ceiling, carpet, windows, etc.)
- Location and type of HVAC equipment supplying the space
- Location of rooms within the building (outside wall, floor for multistory buildings, adjacent room uses, etc.)

The key step in this process is to identify the occupied spaces to be surveyed. The focus should be on occupied spaces where comfort and occupant performance are critical. For office buildings this is where knowledge workers are located; for schools this is in classrooms. It is useful to start by aligning the acoustic spaces with the HVAC zones. Further divisions may then be required to, for example, define open-office plans versus private offices. As experience is gained in identifying the sound-critical spaces, the performance improvement plan should be updated to reflect those details.

Conduct Performance Observation, Measurements, and Analysis

Conduct Occupant Satisfaction Survey

For the Basic Evaluation, the primary measurement is the occupant survey.[iii] Such surveys measure factors that affect occupant productivity, which has operating cost implications for building management. We are relying on the occupants' perceptions for the first level of IEQ assessment, as they can report on unsatisfactory IEQ conditions that might not be observed by a one-time walk-through. Occupants' experiences change somewhat from season to season and in response to daily HVAC loads and other activities, but their responses to the typical occupant survey integrate their perceptions ranging back more than three months, so two seasons are usually reflected in the responses.

The occupants are surveyed to

- determine occupant satisfaction with the indoor environment,
- determine the impact of IEQ on their ability to do their work (productivity), and

iii. Note that many organizations have limitations on collecting data on human subjects. Any occupant survey administered should abide by the organization's rules in this area.

- establish a checklist of performance issues used for diagnosing causes of problems revealed by the first two questions.

The occupant survey can be conducted by one of two automated methods:

- the Occupant Indoor Environmental Quality (IEQ) Survey™ at www.cbe.berkeley.edu/research/survey.htm by Center for the Built Environment (CBE) at the University of California at Berkeley (CBE 2008) for the US and
- the Building Use Studies (BUS) Occupant Survey at www.usable buildings.co.uk/WebGuideOSM/index.html by Usable Buildings Trust (UBT 2008) for the UK and Europe.

The complete CBE survey, instructions for its use, and an example report are included in Appendix C. The CBE survey is administered via the Web on occupants' computers and the results are automatically tabulated; ~~it~~ can be administered manually via e-mail or paper copy or in interviews ~~and~~ the results are tabulated manually or by spreadsheet. It should be noted that conducting an automated survey is much less expensive than conducting a manual survey. To enable fully open participation, individual responses to the CBE survey are anonymous and participation is voluntary, ~~which obviates complaints that are normally associated with a manual survey.~~ However, distributing the CBE survey manually may not ensure complete anonymity, particularly if it is conducted by interviews. In this case occupants must be explicitly informed that their participation is voluntary. It is recommended that building spaces be broken up in areas with six or more occupants to mask individual identities.

The same questions are used for either the CBE or the manual survey so that the building can be benchmarked against the CBE database of similar buildings. Sample survey questions include the following:

- How satisfied are you with the (temperature/air quality/lighting/acoustics) in your workplace? (Answer is on a seven-point scale from Very Satisfied to Very Dissatisfied, with a score of 4 being neutral.)
- Overall, does the (temperature/air quality/lighting/acoustics) in your work space enhance or interfere with your ability to get your job done? (Answer is on a seven-point scale from Enhances to Interferes, with a score of 4 being neutral.)
- ~~What control do the occupants have over their lighting and their level of satisfaction with~~
  - ~~the amount of light in the work space,~~
  - ~~visual comfort, and~~
  - ~~the overall lighting quality?~~
- ~~What is the occupant's level of satisfaction with the following lighting control items:~~
  - ~~Light switches~~
  - ~~Automatic daylight controls~~
  - ~~Occupancy sensors~~
  - ~~Shading devices on windows~~

At a minimum, the building management should survey the building occupants on an annual basis. In seasonally diverse climates, consideration needs to be given to conducting surveys on a seasonal basis. If the survey indicates dissatisfaction votes or negative comments for more than 20% of the occupants in a given area of the building, the building management should take corrective action. If the survey indicates dissatisfaction for between 10% and 19% of the occupants, the building management should evaluate and consider taking appropriate corrective actions. If the survey indicates dissatisfaction for less than 10% of the occupants, the building management may assume that the building IEQ is generally acceptable but should evaluate individual comments and address them as appropriate. Over time the survey responses should be compared to determine if there is any indication of a trend, either positive or negative. An acceptable outcome is that the results of the survey do not decline (become worse) over time.

If an occupant expresses some level of dissatisfaction with any IEQ aspect in his or her work space, the online CBE survey asks a second level of questions about that aspect to diagnose the source of the dissatisfaction. The following example questions help identify the nature of the problem and the features of the building and its operation that contribute to that problem.

For thermal comfort, the second level of questions include the following:

- In warm/hot weather is the temperature often too hot or too cold?
- In cold/cool weather is the temperature often too hot or too cold?
- At what time of the day is this a problem?
- Is it a Monday morning or weekend problem?
- Are direct sunlight or hot/cold surrounding surfaces causing discomfort?
- My area is hotter/colder than other areas?
- The thermostat is inaccessible or controlled by other people?

For IAQ, the second level of questions include the following:

- Is the air stuffy or stale?
- Is the air not clean? Is there excessive dust from the ventilation system or other sources?
- Are there unpleasant odors?

For lighting/daylighting, the second level of questions include the following:

- Is the space too dark or too bright (contrast)?
- Is the amount of daylight sufficient?
- Is the amount of electric light sufficient?
- Is there noticeable flicker?
- How is the color of the lighting?
- Is task lighting available?
- Are there reflections on computer screens?
- Are there distracting shadows?

By comparing the first- and second-level responses to the survey against the CBE database, one can determine if there is enough of a problem to require additional action. The first action in many cases will be to determine the *cause* of the problem.

Using a lighting example, if occupants have indicated an overall dissatisfaction with the lighting quality and have indicated that the color of the lighting is an issue, then this could mean any of several scenarios:

- They could be objecting to the overall color of lighting, which indicates that the color temperature of the light sources needs to be reviewed.

- They could have a problem with the color rendition of people or objects in the space (they feel the color of objects does not appear true), which indicates a need to review the Color Rendering Index (CRI) of the lamps used.
- They could voice concern over spaces where different luminaires are emitting different colors, which typically indicates a maintenance issue and involves putting procedures in place regarding what lamps are ordered for use as replacement lamps.

The following questions may identify sources of acoustics dissatisfaction:

- Can you overhear other people talking on the phone from one work space to another?
- Are you distracted by persons talking in neighboring areas?
- Are others overhearing your private conversations?
- Is the noise from the office equipment (telephones, copiers, etc.) or lights unacceptable?
- Is the mechanical equipment (heating, cooling, and ventilation) noise unacceptable?
- Is speech difficult to understand because of echoing of voices and other sounds?
- Can you hear noise from adjacent rooms through the wall, ceiling, or ductwork?
- Can you hear noise from the outside through the walls, windows, or ventilation openings?
- Are you disturbed by footfall noise from the floor above?

Note that many of these problems can usually be corrected without professional services; the remaining items may require outside services.

Review Building Maintenance Log

If a building maintenance log exists that includes occupant IEQ service issues, this log should be reviewed for those issues. Building zones where problems are occurring should be noted and compared to zones without problems; this will identify areas for focus during the building walk-through. The frequency and nature of the issues give a sense of the nature of the problems. Are there conflicting requirements for different occupants within any given zone? This might indicate individuals' physiological thermal, lighting, or acoustical perceptions that need attention. Any unresolved issues should be noted for follow-up.

Service issue logs are not equivalent to surveys in measuring performance or in comparing against benchmarks. They reflect only a subset of the population who are dissatisfied, have judged that the situations warrant informing facilities personnel, and expect that corrective action will be taken.

Conduct Walk-Through

The next step in the Basic Evaluation for IEQ is to inspect the facility, seasonally if not monthly, for indicators of building performance (by room or major zone). Some physical measurements may be taken during the observational walk-through. Instruments used might include a meter for surface temperatures, an inexpensive temperature and humidity meter, an illuminance meter, and a sound level meter.[iv] The Walk-Through Checklists and Recommended Corrective

Actions shown in Appendix A provide a systematic structure to ensure that performance improvement opportunities are addressed. Interactive spreadsheets are available on the accompanying CD.

Performance indicators may be visual clues of building failures (water stains on ceilings and walls or mismatched color temperature bulbs in the lighting fixtures) or the clues may be evidence of occupants having taken action to modify their environment. If possible, ask occupants why they may have taken the actions you observe. There may be alternative causes for an action that would be good to understand (e.g., closed shades may indicate a visual problem—glare—or a thermal one—direct solar heat on the occupant; personal headphones or earbuds may indicate an acoustic privacy or intruding noise problem). However, if occupants have taken actions not allowed by policy (such as bringing in personal heaters or tampering with controls), do not ask about those but document them for future reference. Occupants have usually taken the observed actions because the building IEQ is impeding their getting their jobs done.

Also, don't expect that you will necessarily experience the IEQ issues noted in the survey or service issue logs, because the issues may have occurred only during certain building system operating conditions that may not be present during the walk-through. The occupants will often uncover the sources of the issues if asked. Some example observational questions and/or issues specific to each IEQ category (thermal comfort, IAQ, lighting/daylighting, and acoustics) are summarized in the following list; follow the detailed checklist items and recommended corrective actions in Appendix A for a comprehensive listing. A review of the form prior to the walk-through will help guide what to look for.

Thermal comfort items include:

- *Positions of shades and blinds under known solar conditions:* Shades are often lowered for a purpose and not returned after the condition passes, negating daylight harvesting opportunities for long periods of time. (Take photos.)
- *Glazing attachments:* Look for cardboard or foil taped to window glass.
- *HVAC system tampering:* Are personal radiant heaters or desk fans in wide use? Are vents or diffusers taped over? Have thermostats been tampered with?
- Are occupancy sensors taped over? (Take photos.)
- Is there any indication that office equipment is causing thermal problems?
- Have the service issue logs indicated thermal problems in this area?

Other considerations include the following: Does the HVAC system control system allow trend-logging of zone temperature readings or setpoints? Is it readily available and does anyone use it? Too often this essential performance measurement tool is inaccessible to normal users or requires a software upgrade from the controls manufacturer.

IAQ-specific observational issues fall into the following categories and should be accompanied by appropriate corrective actions:

- Ventilation system
- Moisture management
- HVAC system

iv. Measurement details will be covered in the Diagnostic Measurement section.

- Building pressurization
- Dirt and contaminant capture.

TO THE COMMISSIONING TEAM

Sidebar should go near the IAQ specific items listed.

Regarding the IAQ-specific issues identified herein, note that these are all related and should be considered part of an integrated HVAC system. Thus, the five components discussed for IAQ should not be considered separately, but as part of an integrated operating system.

Ventilation System: The following steps should be used to inspect the ventilation system:

1. Observe that outdoor air (OA) intake dampers are not closed.
   Note: At the Diagnostic Measurement level, the proper operation of the OA damper should be confirmed, either manually or by use of the BAS.
   - From the building baseline information, determine the total number of HVAC units; the number of units to be inspected each month is 10% of this total.
   - Locate the OA intake damper. It is typically just inside the exterior wall of the mechanical room of a large air-handling unit (consult the operation and maintenance (O&M) manual if the location of damper is not readily found). For rooftop equipment, if the OA damper is manually operated and accessible from the outside, observe its position. If it is not accessible from the outside, open the door of the unit closest to the OA louver and observe the damper position. If it is a motorized damper, adjust the damper linkage or change the software setpoint. Note that most motorized OA dampers will automatically close when the HVAC unit is shut down.
   - If there is an access door, open it carefully, taking all appropriate safety precautions, and verify that the damper is not in the closed position and is not damaged.
   - If no access door exists, observe the position of the damper actuator and verify that the connections are tight and that the linkage is not damaged. Mark the damper shaft position for future reference.
2. Inspect OA louvers/plenums for dirt/debris/clogging/snow.
   - On larger air-handling units, the OA louver is located on the exterior of the building or penthouse. On smaller rooftop units or packaged units (fan coils), the louver is on the exterior of the unit (review the O&M manual if there is any question regarding the location).
   - Observe the condition of the louver and, if there is any dirt, debris, snow, or other material restricting the airflow, document the condition and clean the louver.

Moisture Management Inspection: Inspect for water/moisture/condensation inside the building and water intrusion into the building—cover 10% of building area per month. Each month inspect an area for the following indications of water damage:

- Any staining/discoloration of acoustical ceiling tiles, walls, or flooring.
- Any standing water in bathroom fixtures or in the janitor closest.
- Any moisture/condensation on the interior of windows and doors.

Investigate the cause of any of the above and take corrective action.

HVAC System Inspection: The following steps should be used to inspect the HVAC system:

1. Inspect the HVAC equipment filters and drain pans—cover 10% of the filters and drain pans each month.
   - Taking appropriate safety precautions, open the HVAC equipment access door to the filter section (if unsure of the location of the filter section, consult the O&M manual) and observe the condition of the filter(s). Observe whether there are gaps that allow bypass or if filters are missing. Document with photographs. If the filters appear dirty or missing, replace them.
   - Taking appropriate safety precautions, open the HVAC equipment access door that will allow observation of the unit's drain pan (if unsure of the location of the drain pan and/or the access door that will allow observation, consult the O&M manual). If the condensate pan is retaining water, make sure the drain is not plugged and that the pan is properly pitched to ensure drainage. If the pan is not properly pitched, have it replaced or modified. If the drain is not plugged and the pan is pitched so as to ensure drainage, consult the O&M manual to determine if the drain trap is properly sized. If the trap is not properly sized, have it replaced with one that meets the HVAC equipment manufacturer's recommendation. Pan pitch and/or drain trap replacement should be included in the inspection report as maintenance action items.
2. Inspect any area where exhaust is used, specifically bathrooms, copier areas, kitchens and other food preparation and consumption areas, and janitor closets. Conduct a tissue test: locate the exhaust grille and hold a tissue near the grille opening, observing the movement of the tissue.
   - If the tissue is drawn to the grille opening, the exhaust system is operating.
   - If the tissue drops away from the grille opening, the exhaust system is not operating properly; investigate further and make necessary corrections or repairs.

Building Envelope/Pressurization: The following steps should be used to inspect the building envelope and pressurization:

1. To verify that building pressurization is not negative, conduct a tissue test at the exterior door on a calm day. Slightly open an exterior door and hold a tissue near the opening. Observe the deflection of the tissue.
   - If the tissue is deflected toward the outside or is not deflected, the building entrance is neutral or positively pressurized.
   - If the tissue is deflected toward the inside, the building entrance is negatively pressurized. If this is the case, the pressurization can be corrected by rebalancing the system (supply and exhaust), increas-

ing the amount of OA provided to the building. Report this condition in the inspection report.

2. Inspect housekeeping, cleaning chemicals, and pest control chemicals; verify that they are not stored in air-handling unit rooms or plenum spaces but in rooms properly constructed for storage of chemicals. These rooms should be fully isolated from adjacent spaces and should have adequate and independent ventilation.

Dirt and Contaminant Capture: The following steps should be used to inspect the building for dirt and contaminant capture:

1. Inspect entrance area walk-off mats and grates.
    - Inspect all walk-off mats; if dirty or missing, clean and/or replace them.
    - Inspect depressed walk-off grating systems; if dirty, clean them. If water is retained, investigate and correct the problem.
2. Inspect janitor closets or other areas where chemicals may be stored.
    - If any of the following are observed, take corrective action: open containers, spilled chemicals, retained water and/or chemicals in sinks, and/or blocked air intake grilles indoors.
    - Inspect closet exhaust per the previous HVAC System Inspection section.
3. Inspect kitchens, cafeterias, and break areas where food may be prepared or consumed.
    - If any of the following are observed, investigate and take corrective action: open food containers, spilled food, retained food, dirty items and/or standing water in sinks.
    - Inspect food preparation exhaust per the previous HVAC System Inspection section.

The lighting section of the walk-through checklist includes the following broad categories, which should be accompanied by appropriate corrective actions:

- Lighting and control issues
- Daylighting issues
- Visual acuity issues

The goal of the walk-through is to both observe hard problems and look for more subtle indicators of lighting issues not necessarily directly observable. While the walk-through can be conducted as a purely observational process, discussions with occupants during the walk-through will generally result in a more accurate list of issues.

Some of the lighting problems found while using this checklist are easily corrected by simply moving light fixtures or furniture, changing purchasing practices, and other similar activities. However, some of the lighting issues will be sufficiently complex in nature to require a more technical approach, such as those described for the Diagnostic Measurement or Advanced Analysis levels. These activities may require the use of a lighting professional to analyze the issues and to make the corrections.

Acoustic walk-through observations are done by listening, remembering that occupants' dissatisfaction usually is related to the following concerns:

- Background noise from HVAC and office equipment.

- Noise intrusion from adjacent spaces and outside noise sources.
- Acoustic privacy between work spaces (particularly important when confidential information is discussed).
- Speech intelligibility in classrooms, lecture halls, and conference rooms.

The acoustics section of the Walk-Through Checklist and Recommended Corrective Actions Form in Appendix A offers the benefit that additional observations can be made if acoustic issues are identified. Some acoustic issues only occur during specific building system operating conditions. Likewise, intruding noise from the outside or adjacent spaces may only occur during certain times of the day. Interviews with occupants will often identify the sources of these issues.

Conduct Performance Comparisons (Benchmarking)

To Past Performance

If previous occupant surveys exist, compare the current survey data to that of the previous survey. In addition to comparisons of the quantitative survey results, comparisons of previous field observations against current observations should be made. Any degradation in occupant satisfaction or changes of the physical layout should be noted for follow-up. The diagnostic questions will offer insight into the nature of the dissatisfaction.

To Baseline Databases

Current performance, with regard to the occupant survey results, should also be compared to the CBE database on IEQ (thermal comfort, IAQ, lighting/daylighting, and acoustics). Comparing the composite results against the CBE database helps determine if additional action is required. This is particularly important for rated or high-performance buildings—the quality of the occupants' environment should not be compromised for the sake of energy performance.

Although the occupant satisfaction scores are the primary quantitative metric for performance evaluation, field observations can also give a semiquantitative measure. If walk-through field observations exist from peer buildings, note any indication of trending, particularly any increase in comments or in observed issues, both in terms of frequency and intensity.

The occupant survey allows the performance of your building to be compared to that of a large database of peer buildings. Results are tabulated according to mean scores for occupant satisfaction. The comparison can be against all buildings and also against a filtered set of buildings of similar type. Filtering for peers is accomplished as follows: The CBE database of IEQ questions can be subdivided for office buildings, schools, retail locations (answered by employees, usually not customers), hospitals (answered by nurses and staff, not patients), and laboratories. A filtering tool for peer building types is available to the user. Examples of such filtered results are given in Appendix C. Benchmarking performance uses graphics such as cumulative distributions of the building's survey responses or histograms with standard deviation bars; examples are given in Appendix C. These are automatically reported by the survey.

Identify Issues Needing Correction and Take Corrective Actions

The next step in the Basic Evaluation for IEQ is to identify performance issues, determine their root causes, make a plan to remedy them, and take the necessary actions. The actions could be very diverse, affecting hardware or operating procedures or involving behavior modification suggestions to occupants. Issues likely to be encountered, and their root causes, are outlined by IEQ category in the rest of this section; these issues and recommended remedial actions are presented as a detailed, step-by-step list in the checklists shown in Appendix A.

This list uses the same IEQ categories and items addressed in the Walk-Through Observations subsection under the Performance Measurement Procedure heading of this section. In some cases, the reader will be directed to the Diagnostic Measurement or the Advanced Analysis level, where the services of a professional with IEQ expertise are needed.

For thermal comfort there are three categories of corrections or adjustments to be considered:

- Fenestration problems
- HVAC problems
- Other problems

The HVAC problems may simply involve corrections to thermostatic controls, and the following basic efficiency measures should be implemented regardless of the results of the comfort survey.

- Replace standard wall thermostats with programmable thermostats for buildings that do not have communicating temperature control systems.
- Use higher setpoints for summer and lower setpoints for winter. Differentiate occupied and unoccupied periods. For example, in summer, 78°F occupied, 84°F unoccupied; in winter, 72°F occupied, 64°F unoccupied. Use a 6°F minimum dead band between heating and cooling setpoints.

Comfort corrections based on survey responses, service issue logs, and walk-through inspection

- Use *diagnostic page checkbox scores* to identify causes of problems, and use the occupants' background data to determine in what sections of the building the problems are found.
- Review *occupant comments* to identify causes of problems.
- Prioritize the problems to be corrected. Do the simplest, cheapest, and most effective solutions first. Examples of such measures include changing setpoints, flow rates, and window films; adjusting diffuser vanes; and ~~provisioning~~ graphic trend data capability to the control system (~~the latter~~ may be done in a report; see the Report Results section later in this chapter).
- Check the Diagnostic Measurement and Advanced Analysis sections for more detailed information on problem analysis and solutions.
- Arrange to have the corrections and adjustments made.

For IAQ one should take action to correct the issues presented in the IAQ checklist shown in Appendix A or, if there is not a straightforward correction, conduct additional investigations as recommended at the Diagnostic Measurement and Advanced Analysis levels to better determine appropriate actions to be taken. The five issue categories in the IAQ section are the following:

- Ventilation
- Moisture management
- HVAC systems

- Building envelope/pressurization
- Dirt or contamination

The listing in the lighting/daylighting checklist shown Appendix A addresses the issues covered in the survey and the walk-through. For each question answered "yes," the local occupants should be asked about the issue to determine what they feel the problem is and how critical it is to them. The five issue categories in the lighting/daylighting section include the following:

- Quantity/quality of light
- Glare
- Controls
- Lamps and ballasts
- Maintenance

For many of these issues, specific recommended actions are provided to attempt to mitigate the problems; usually these actions can be performed by in-house personnel. However, in all cases, when local occupants indicate that the problem has to do with the light levels (or when the recommended action has been unsuccessful), it is probably best to proceed to the Diagnostic Measurement level to confirm light levels and then to the Advanced Analysis level to have an outside consultant provide solutions. For issues such as glare and lamp color, it is usual best to proceed directly to the Advanced Analysis level.

The results of the occupant survey and the walk-through (see Appendix A) provide a first-order diagnosis of acoustic issues. Some of these issues may be corrected with little cost or outside help. For example, a common acoustic issue in open office spaces is related to telephone use. This issue can sometimes be resolved with basic training on telephone etiquette, identification of acoustically isolated spaces for private conversations, or the introduction of new telephone equipment.

Many sources of acoustic dissatisfaction are related to the design of the building. For new buildings these issues are usually resolved during the design and Cx process. Subsequent sources of acoustic dissatisfaction may result from redesign or remodeling of the building, particularly those that change the use of the interior space. These issues may be more difficult to correct.

The acoustics checklist shown in Appendix A addresses four issue categories and includes a detailed list of potential acoustics issues and recommended corrective actions. The four issue categories are these:

- Background noise
- Noise intrusion
- Acoustic privacy
- Speech communication

The following is a summary of common acoustic problems in commercial buildings and recommended actions.

Speech privacy is the number one source of dissatisfaction in commercial buildings. Speech privacy is a "signal-to-noise" issue; i.e., it is determined by both the level of the intruding speech and the room background noise at the listener's ear.

- *Background noise:* Sometimes the listener's space is too quiet for privacy and would benefit by increased background noise. A baseline of background noise is usually provided by the HVAC equipment. Added sound can be provided by electronic masking. Changing the background noise in a space usually requires Advanced Analysis measurements (see the IEQ Acoustics section in Chapter 4) and analysis by a consultant.

- *Room reverberation:* Sometimes the space can be too reverberant or sound reflective. This is particularly true of spaces without a sound-absorptive ceiling system. Web-based tools are available from building interior suppliers that can calculate the reverberation of a space and benchmark results against speech communication/privacy metrics. Excessive room reverberation can sometimes be corrected by technically knowledgeable owner personnel together with an interior products supplier. Simple changes can be handled by the building owner and are discussed for the Diagnostic Measurement level (see the IEQ Acoustics section of Chapter 3). If modifications are extensive, Advanced Analysis measurements and analysis by a consultant are recommended.
- *Room isolation:* Sometimes the background noise and room reverberation are acceptable and the problem is the level of the speaker's voice. This usually results from inadequate sound isolation of interior partitions. Solving this problem requires that Advanced Analysis evaluation be conducted.

HVAC equipment noise may be a source of dissatisfaction that is often related to the building's mechanical design, including noise-producing equipment, the air distribution system, and building controls. These issues usually require Diagnostic Measurement assessment followed by Advanced Analysis actions.

Noise intrusion from outside or adjacent spaces may also be a significant source of dissatisfaction. Noise intrusion from the outside can be related to the building orientation to outside noise sources, ventilation ducts, and windows and other fenestration. Interior noise intrusion is usually a symptom of inadequate sound isolation between rooms. These issues are related to architectural details and Advanced Analysis evaluation by a consultant is recommended.

Remeasure Performance

Repeat the occupant survey to determine the effectiveness of the corrective actions. Problems are usually isolated within certain areas, so the survey need only be repeated in the affected areas (typically where a high concentration of comments occurred). A simple walk-though and an interview of the occupants may be all that is necessary to determine if these actions have resolved or at least partially mitigated the issues.

Preferably, conduct repeat surveys around the same time of year to have the occupants experience similar outdoor conditions each time. Consider instructing the occupants (in the survey invitation) to identify the time period they should recall when they answer the questions. Compare results to those obtained before the corrections or adjustments were made to verify that the problems have been addressed and performance has improved. If corrective actions for lighting or acoustics require Diagnostic Measurement or Advanced Analysis evaluation, then follow-up measurements by a consultant may be appropriate.

Compare New Performance to Past Performance

Annually, or after any corrective actions are completed, current performance scores should be compared to past Basic Evaluation performance. Any degradation of occupant satisfaction should be noted for follow-up. The diagnostic questions will offer insight into the nature of the dissatisfaction. Records should be kept of the improvement measures and other significant changes to the building or its occupancy between the surveys.

~~Conducting repeat thermal comfort surveys around the same time of year to have the occupants experience similar outdoor weather conditions each time is not a strict requirement for evaluating thermal comfort in air-conditioned buildings. It has more effect in naturally ventilated and mixed-mode buildings with operable windows, where the occupants' connection to outdoor climate is closer. In either case, it may be more beneficial to obtain the results of the repeat survey sooner than to wait for climate consistency~~. Include a photographic record of changes to building envelope or furnishings or of occupant-installed corrections to perceived problems. In cases where photographs were taken in a previous evaluation, displaying before and after photographs in matched pairs is effective.

When comparing the pre-correction survey to the post-correction survey, if there is a reduction in dissatisfied votes or negative comments to below the 10% threshold, it can be assumed that in general the IAQ issues have been addressed. However, consideration should still be given to any remaining or new comments. If the follow-up survey results in an increase in dissatisfaction, field observation should be conducted again, with the recording party paying particular attention to any insights provided by comments directing the observation to specific actions. If the new observations do not reveal any improper conditions, conduct additional investigations as recommended at the Diagnostic Measurement and Advanced Analysis levels.

If the lighting issues were not resolved, then these items, along with those previously identified as needing additional assistance, should be presented to an outside source for solution. Secure the services of a professional with lighting experience to review the results and prepare a scope of work for correction of the issues. It is important to hire a person or firm with the correct expertise to address the issues that have been identified. One source is the International Association of Lighting Designers; they can be contacted for information on local resources who could be engaged to work on the solutions. Selection of a lighting consultant is described in the Advanced Analysis procedures of Chapter 4.

For acoustics issues, not all the occupied spaces need to have the survey repeated every year. Acoustic concerns tend to be isolated to certain areas; only these need to be surveyed on an annual basis. Likewise, if any area is remodeled or the activities of the occupants change, those spaces should be surveyed upon completion of the project.

Report Results

At the completion of the Basic Evaluation process, report to the building stakeholders (management, building operators, and the occupants) the results of the surveys and field observations as well as the corrective actions taken. This will reinforce the effect that IEQ issues have on company performance and the importance that the company or organization associates with them. Comparisons of the IEQ performance before and after the corrective actions can be done with the survey reporting tool, which generates a graphic report automatically. The rate of entries in service issue logs can also be tallied. Photographic evidence of improvements (the matched pairs of before and after photographs previously mentioned) should be included. A recommended report template is shown in Appendix B and included in the Performance Measurement Report Template Word file on the companion CD.

The report should include the following descriptions of results of the initial and follow-up occupant surveys and corrective actions taken:

- Describe building features (this may overlap with other areas such as energy and lighting/daylighting).
- Describe HVAC and lighting systems and their controls.
- Is trend reporting available? Is the format graphic? Is it used by operators? (This is the foremost requirement with which one can reach high performance.)
- Report benchmarked satisfaction survey responses with graphics (this is automatically generated by the CBE survey).
- Report benchmarked productivity impacts from survey results (this is automatically generated by the CBE survey).
- List occupants' open-ended comments, organized by survey section (this is automatically generated by the CBE survey).
- Describe the trends. (Have things become better or worse since the last survey?)
- Report the nature of service issue logs and the corrective history.
- Report the main findings from interviews with the operator (if there is an operator this is essential).
- Report unresolved issues that may require expertise; identify the next level of attention.

Make recommendations regarding the following:

- Building envelope, space, and furnishings improvements. (Costs?)
- System improvements at the zone level (e.g., programmable thermostats, trend logging in the BAS, changes to diffusers). Improvements to controls and operational data visualization capability
- Operational changes to setpoints and schedules. (Are corrections in place?)
- Occupant information interface: trend data visualization, show dashboard options.
- In general, does the level of performance suggest a change in maintenance contracting? Awarding them a bonus?
- The company/organization procedures changed as a result of this effort
- The company/organization procedures that need to be reinforced in order to reduce or eliminate a reoccurrence of IEQ issues.
- Next-level actions for unresolved issues. These might be carried out by contractors.

Building owners, operators, and occupants should be made aware of the success of corrective actions in resolving sources of IEQ dissatisfaction. Lessons learned from corrections in one particular problem area can often be applied to other buildings or interior spaces. If corrective actions require further diagnostics or the services of a consultant, the report should make this recommendation. In such cases a detailed report is usually required.

TOOLS AND AIDS

Detailed tools and aids for thermal comfort, IAQ, lighting/daylighting, and acoustics to assist with the IEQ Basic Evaluation procedures are shown in Appendices A–G and are included on the companion CD. Of particular importance are the Walk-Through Checklists and Recommended Corrective Actions for all four IEQ categories that are Appendix A. Further tools common to all IEQ categories include a Report Template (Appendix B), IEQ Occupant Survey (Appendix C), Basic Evaluation Measurement Plan Form (Appendix A), and Building Characteristics Form (Appendix A).

Diagnostic Measurement Procedures 3

ENERGY

INTRODUCTION

At the Diagnostic Measurement level, performance measurements are more focused than at the Basic Evaluation level in that submetering is used along with the procedures of the equivalent of an ASHRAE Level II energy audit (ASHRAE 2011b). Submetering building subsystems is used in addition to whole-building metering, and data is analyzed over shorter time intervals (typically monthly, weekly, and daily, sometimes supplemented by hourly or subhourly data) in search of energy improvements. The energy audit task is more detailed and requires the use of physical measurement and instruments, augmented by calculations, by a person experienced in energy use and cost analysis measures. Target energy reduction goals are set and energy efficiency measures (EEMs) having a simple payback of three to five years are identified.

TO THE COMMISSIONING TEAM

Sidebar should be placed near the beginning of Chapter 3.

During the planning phase of existing building commissioning (EBCx), development of the expanded performance measurement plan should include the commissioning (Cx) team. Working with building management, the Cx team is in an ideal position to conduct or oversee these Diagnostic Measurement procedures. These measurements and associated analysis provide tools for the ongoing operation, maintenance, and modification of the building and its assemblies and systems.

PERFORMANCE MEASUREMENT PROCEDURE

The Figure 3-1 flowchart illustrates the energy performance measurement procedure at the Diagnostic Measurement level.

Expand Performance Measurement Plan

Just as in a Basic Evaluation program, the first step is to develop a performance measurement plan. Its purpose is to identify the resources needed to carry out measurements at the Diagnostic Measurement level and to establish the plan's expected deliverables.

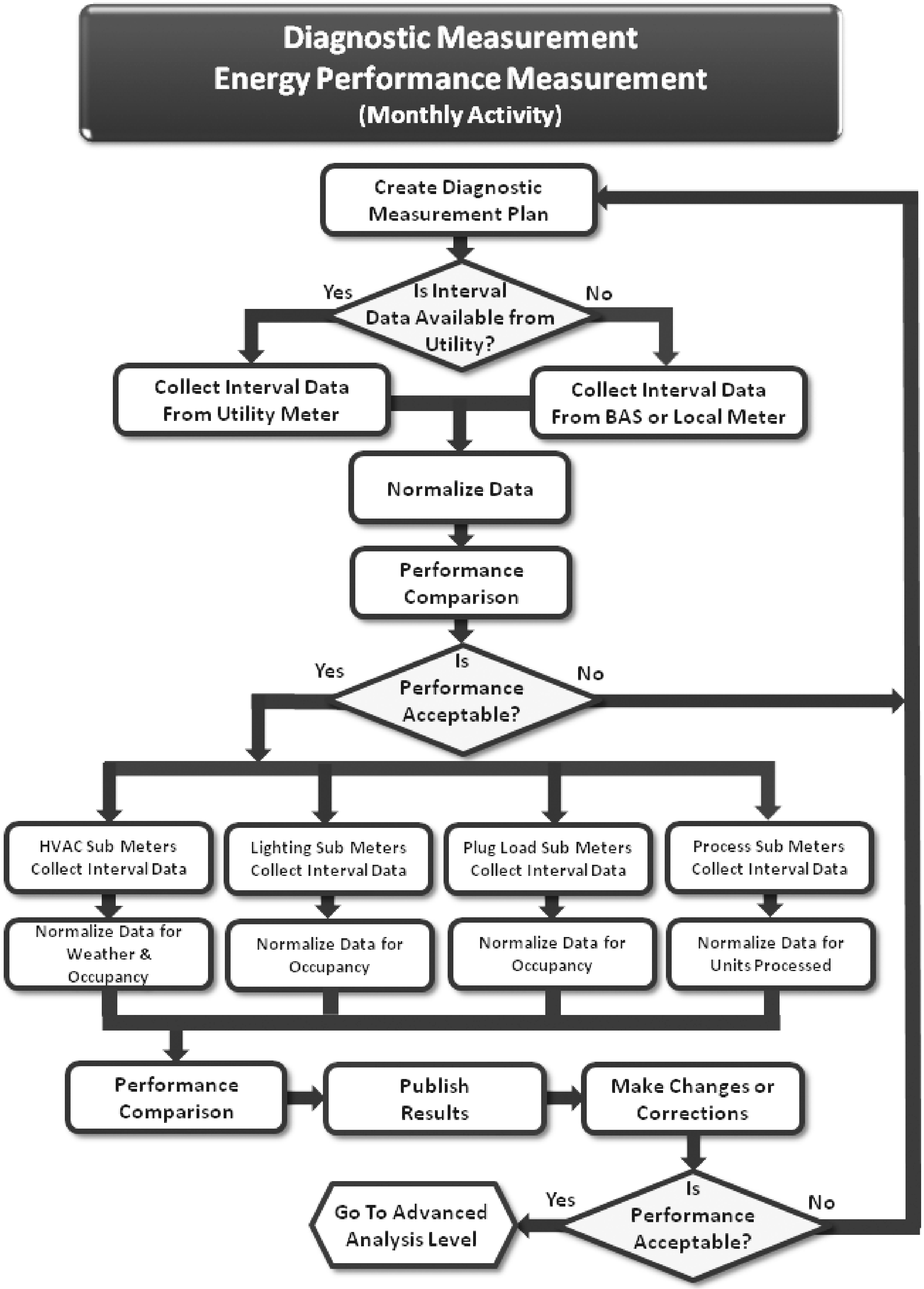


Figure 3-1 Energy Diagnostic Measurement Performance Measurement Procedures

A person most knowledgeable in the building's day-to-day operation should lead a core group of the building management team to establish and implement the Diagnostic Measurement program. Seek out partners, including all utility providers, key tenants, key department representatives, and outsourced service vendors, to develop the plan details and obtain buy-in from employees and other building users. Key personnel include those who bring intimate knowledge of their work spaces. Outsourced vendors include technicians with energy analysis and ASHRAE Level II audit (ASHRAE 2011b) experience. Certification programs, such as ASHRAE's Building Energy Assessment Professional program (ASHRAE 2012), can offer assurance that service providers are qualified.

The Diagnostic Measurement plan should be accurate and thorough enough to be understood. It should also acknowledge a commitment to fund the cost of its performance at about \$5000 to \$10,000, or \$0.10/ft^2 (\$0.93/m^2). It is recommended that the Diagnostic Measurement plan be implemented by first installing submetering based on the Basic Evaluation benchmarking and walk-through findings, and then conducting an energy audit using the metered data for its analysis. The plan should contain at least the following elements:

- Written notice to occupants explaining the measurement plan and encouraging their active support.
- Posted schedule of energy audit inspection dates and times.
- Preestablished checklist of typical energy audit tasks with prerequisite data sheets for users to fill out. (See Appendix A for sample checklist.)
- Identification of all energy sources to be submetered over a period of no more than one year.
- Identification of a specific energy reduction goal.
- ASHRAE's *Procedures for Commercial Building Energy Audits* (2011b).
- Establishment of the time period for measurement to be monthly, weekly, daily, and/or hourly or subhourly, if available from the local utility.
- Selection of specific submetering points and installation of submeters.
- Consideration of installing a building automation system (BAS) for collecting the large amount of data needed. If BAS installation is selected, be sure the BAS has adequate capacity to measure all the electrical submetered points at 15-minute intervals. Other submeters should be cumulative devices, reportable in hourly graphical form and cumulative for at least one full year.

If submetering has not yet been installed, analytical techniques are available to estimate major energy-use components. Procedures for assessing system energy use by major end-use category and software to conduct such an assessment are are presented in *CIBSE TM22, Energy Assessment and Reporting Method* (CIBSE 2006). Design or other known system data can be entered into the program and the software will use benchmark data to distribute unallocated energy use. However, it should be noted that estimates are not as accurate as submetered data and should be used only where measurements are not feasible.

Collect Building Information

The Diagnostic Measurement level builds on the energy data gathered in the Basic Evaluation level benchmarking exercise by collecting data at more detailed time intervals, typically monthly, weekly, and daily, sometimes supplemented by hourly or subhourly data, if available. Where the local utility is metering electronically, 15-minute-interval data are available for most buildings larger than 10,000 or 20,000 ft^2 (930 or 1860 m^2). Use of interval data can be relatively simple and very valuable as a diagnostic tool; however, at this level it is not necessary and may be more appropriate at the Advanced Analysis level.

Physical data about the building also need to be collected during Diagnostic Measurement to identify potential energy-saving measures that have a relatively quick payback. Measures that have a simple payback of three to five years are often found to be acceptable.

Building as-built drawings are an important source of data if they are available. Data collection from such drawings would include the following:

- Building thermal envelope insulation, vapor retardant characteristics, and glazing types.
- HVAC zones.
- HVAC system control sequence/operation.
- Major building air handlers and their locations and design characteristics.
- Major HVAC components (chillers, boilers, etc.) and their design characteristics.
- Major motors for fans and pumps and their locations.
- Reflected ceiling lighting plans and lighting schedules.
- Electric panel schedules (for submetering points).

The next step of data gathering consists of verifying the actual building data by conducting a hands-on inventory of systems and equipment and selecting the metering methods to be used.

Conduct Performance Observation, Measurement, and Analysis

After collecting the above building data, install any submetering and collect its measured data. Depending on what is being measured, the collection period could be anywhere from 24 hours to a week or a season but no longer than one year.

When choosing submetering, major end uses should be considered as well as specific component energy uses. Major end uses include HVAC (heating, cooling, fans), lighting, plug loads, and process loads. A good time to install permanent submeters is during a renovation. If permanent submetering is not feasible, consider portable data loggers or using an electrical contractor who already has the instrumentation—you would just pay for its rental for the data collection period. Make sure the meters have the desired accuracy and have been calibrated within the last 12 months.

An example of an end-use monitoring choice is to monitor one switched lighting circuit for 30 days, then change the switch to an occupant sensor and monitor the sensor for 30 days. Compare the cost of the sensor to the cost of energy saved and the increased life of the lamps.

Once the data have been collected, they need to be normalized for weather (degree-days) and/or occupancy, depending on the influence of these factors. Occupancy can be estimated from personnel records, and in some cases security systems may track people flows into and out of the building. However, changes in occupancy from month to month or year to year, such as when tenants are replaced or significant business growth is noted, are more important than absolute occupancy numbers. Occupancy corrections can also be estimated on a floor-area basis if occupancy is difficult to obtain.

One of the best methods for tracking energy performance at the Diagnostic Measurement level is to collect simultaneous energy use and weather data in a form that is easy to track to determine energy performance trends. Because the effects of weather are normalized, changes in energy performance are due to other factors such as operational and occupancy changes. The information provided by this technique is not difficult to assemble and is key for managing energy performance.

To illustrate the use of whole-building normalization of energy consumption data for weather differences, Figures 3-2 and 3-3 show the correlation of cooling degree-days and heating degree-days from local weather data to daily electricity and gas use, respectively. Sample worksheets and graphs used to generate these relationships are presented in Appendix D and included on the companion CD. This normalization allows for weather adjustment of the building's daily energy use by comparing energy use at a particular number of daily degree-days with energy use for a prior year using the degree-days for a comparable day in that year.

Although this type of analysis can use either daily or monthly values to calculate the daily-average relationships, the normalization workbook shown in Appendix D uses monthly data, which can be obtained from utility bills that are readily available. The degree-day weather data can be obtained from sources such as Degree Days.net (BizEE 2012) or the National Weather Service (NOAA 2012).

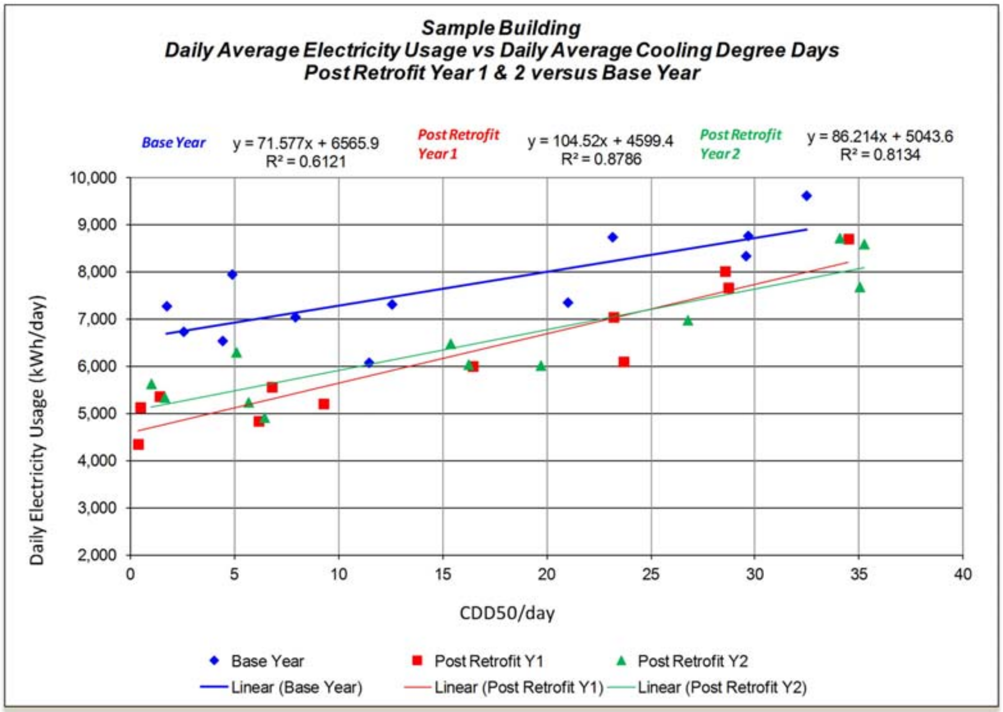


Figure 3-2 Daily Electricity Use vs. Daily Cooling Degree-Days for a Sample Building

Daily presentation of energy and weather data is covered in greater detail in the Advanced Analysis Energy Procedures section.

In the example illustrated in Figures 3-2 and 3-3, the base year was April 2008 through March 2009; this period started soon after construction was completed and the owner was substantially moved in and operating. First-year energy use was monitored and determined to have exceeded estimates. Therefore, from March 2009 through June 2009 low-cost retrofits were made, primarily focusing on adjusting controls in the BAS. Thus, the first full year of post-retrofit operation was July 2009 through June 2010 and the second was July 2010 through June 2011.

Figures 3-2 and 3-3 show the building electricity and gas consumption is substantially lower for both post-retrofit years compared to the base year. Consequently, at a high level these charts answer the primary questions of 1) did the retrofit corrective actions work to reduce energy? and 2) are the energy savings persistent over time? The charts show that not only is energy use reduced in the post-retrofit years but also that the correlations of energy use with weather data are improved. This indicates that the retrofit work was successful in lowering building energy use. We also note that while post-retrofit year 2 shows a slight increase in electricity use compared to post-retrofit year 1, there is a slight decrease in gas use. However, both years are significantly better than the base year, indicating that the retrofits continue to be effective.

The presentation of the measured data can take many forms. The choice should focus on who the reader will be. Management generally prefers simple line, pie, or bar charts and graphs, whereas persons doing the energy savings calculations will likely want more detailed data in an electronic spreadsheet form.

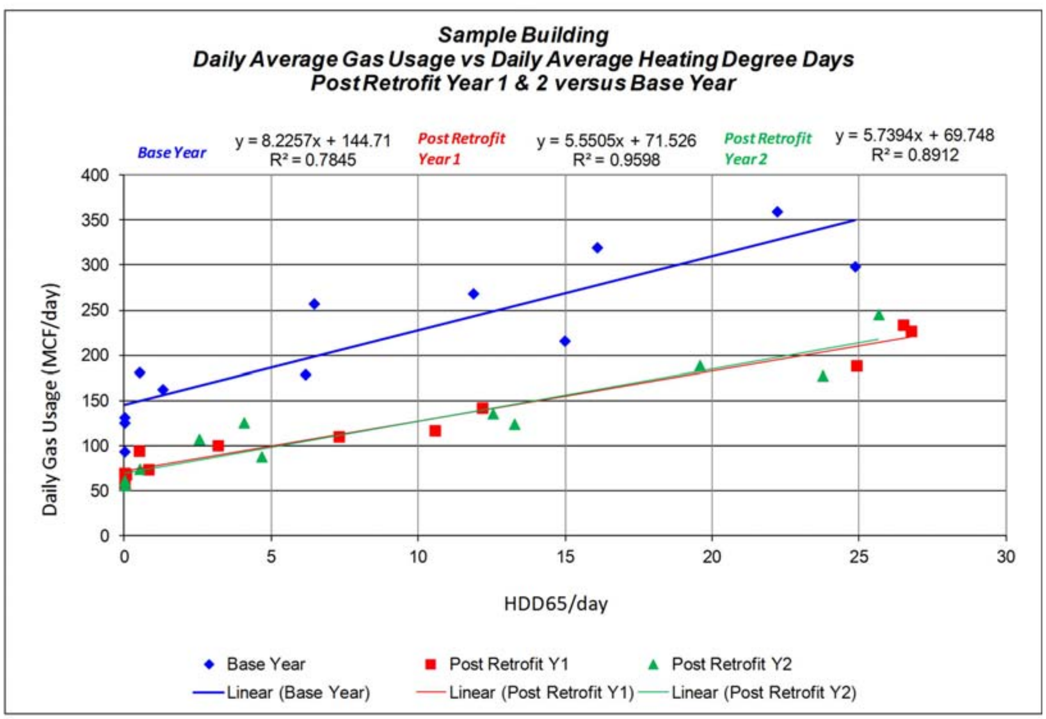


Figure 3-3 Daily Gas Use vs. Daily Heating Degree-Days for a Sample Building

This particular example is simple but exhibits an effective management tool to provide building owners with actionable information they can use to reduce energy usage and costs. If post-retrofit year 2 had looked more like the base year, this would signal that the retrofit corrective actions had been overridden and were no longer working. This information would allow the owner to find out why and take corrective action so that energy performance would return to optimal levels.

Conduct Performance Comparison (Benchmarking)

To Past Performance

It is important to compare energy consumption on a before and after basis. Although cost is important to management, it is more important that energy quantities be compared that show actual energy saved. To measure past performance, use an energy consumption period of one cycle of energy use. For example, if after-hours cleaning is done every Friday, measure the building electric load on one Friday as a baseline for changes you will make for the next Friday. Sometimes chiller performance controls adjustments can be quickly benchmarked in just one day's cycle.

To (Current) Baseline Databases

Sometimes peer buildings are constructed whose energy use can be compared to each other; however, this is rare. Buildings of similar age, HVAC system type, and space use can be compared on a larger energy-use scale, such as seasonal energy use on a unit basis such as energy use index (EUI). More often, the best baseline data will come from the manufacturer of the particular component being measured. Most energy-intensive components such as chillers, boilers, and motors have performance data available for baseline comparison purposes. When presenting the comparable data it is important to state the testing objective as well as the findings outcome. Explain the observations and any abnormalities, including highs and lows. Identify possible problem areas, their magnitude, and likely causes.

TO THE COMMISSIONING TEAM

Sidebar should go near the Make Corrections or Adjustments section for Energy section in Chapter 3.

The HVAC system control sequence/operation is a good source of data to identify operational problems and potential means of performance improvement. In particular, the control sequence can be a basis for the measurement plan for functional testing of the HVAC system, components, and equipment.

Is performance acceptable? If yes, return to start; if no, go to submetering or consider an outside consultant to further evaluate the situation. Reevaluate what is acceptable performance; perhaps the goal set was unrealistic.

Make Corrections or Adjustments

Using the measured data, calculate potential EEMs based on an ASHRAE Level II energy audit (2011b) or similar auditing procedure. Specific guidance for the analysis of retrofits is covered in *Energy Efficiency Guide for Existing Commercial Buildings: Technical Implementation* (ASHRAE 2011a), *Procedures for Commercial Building Energy Audits* (ASHRAE 2011b), and Chapter 35 of *ASHRAE Handbook—HVAC Applications* (2011c). If it is found that a correction or adjustment can yield an energy savings or return on investment of three to five years, then it should be implemented without delay. This may require analysis by a technically experienced person.

- Examples of quick payback measures include relamping and installing variable-frequency drives, demand-controlled ventilation, and occupancy sensors (see example below).
- Other EEM examples include recalibrating and reprogramming controls; repairing faulty components; and cleaning, adjusting, and/or replacing faulty sensors.
- Implement EEMs with a payback of three to five years. Analyze about five to ten EEMs that show the best promise at this stage. Try improved replacement parts, temporary fixes, add redundancy, or explore improved approaches.

Remeasure Performance

Once an energy-saving measure has been put in place, it is important to remeasure and verify the improvement achieved. This includes even small changes to controls settings. If performance is not acceptable, go to the Advanced Analysis level to identify more extensive five- to ten-year-payback EEMs. If performance is acceptable, repeat the remeasurement and verification process annually.

Conduct recommissioning of the EEMs after the first year and again every five years. Note that to track the energy savings of an EEM related to a specific piece of equipment one should follow the procedures of ASHRAE Guideline 14, *Measurement of Energy and Demand Savings* (2002).

Compare New Performance to Past Performance

After performance improvement measures have been implemented it is important to return to the baseline data to clearly assess if the energy savings targets were achieved. This comparison then becomes the basis for Advanced Analysis or reassessment of more reasonable future energy saving targets. These comparison data are also needed for any reports that are developed. Whether good or bad, these results need to be reported.

Report Results

Every EEM, even those just studied but not implemented, should be reported to building managers and occupants. The predicted and measured savings of implemented EEMs should be documented in a report for others to gain an awareness of your efforts to save energy on their behalf and for them to contribute to the efficient operation of the building. As part of the report, a statement of the required routine retest interval for recommissioning the measure should be provided.

Example Illustrating a Retrofit Evaluation

idebar should go in Energy section in Ch3.

The Problem

General lighting is used in a 320 ft^2 (30 m^2) office space. The lighting uses 2×4, 4-lamp, T-12 fluorescent fixtures with magnetic ballasts in a 64 ft^2 (6 m^2) ceiling grid pattern. All are on a standard manual ON/OFF light switch. A clamp-on current transformer with a data logger recorder is connected to the light switch circuit for one week. At the end of the week the data logger showed 50 kWh had been consumed at a demand of 1 kW. As a test, the light switch was replaced with an occupancy sensor and set for a 30 minute AUTO/OFF cycle. Again the data logger recorded the energy use for one week. At the end of the week the data logger recorder showed that 25 kWh had been consumed but the demand remained at 1 kW. What is the value of this installation?

Analysis of Energy and Power Saved

Certainly, this measure is a great EUI saving idea. Each light fixture uses 200 W when on. From a demand standpoint, the data logger showed a demand of 1 kW, which was not a savings, but it showed a consumption usage reduction of 25 kWh during the week. Extrapolated over one year's time, this is an EUI savings of 13.8 $kBtu/ft^2 \cdot yr$ (43.5 $kWh/m^2 \cdot yr$), resulting in a 9% energy savings measure if it were applied to every office space in an office building having an average annual energy use of 150 $kBtu/ft^2$ (470 kWh/m^2).

Analysis of Cost Savings

In some cities the cost of demand alone is \$35/month. Although in this case there is no demand savings, the energy savings at an average of \$0.15/kWh would be \$195 per year. This measure could double the time between relamping from 10,000 to 20,000 hours, yielding a replacement cost savings of up to \$10 per lamp, or \$200 per year. If the occupant sensor installed cost is \$400, this measure has a payback of about one year. Overall this is an energy cost index (ECI) savings of \$1.23/$ft^2 \cdot yr$ (\$13.2/$m^2 \cdot yr$). Not bad for a low-cost measure! It is to be noted that this sample uses data very similar to a typical 1960s commercial office building.

If building design drawings have been affected, they should be revised to ensure proper documentation.

TOOLS AND AIDS

Helpful tools and resources include the following:

- *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency* (FEMP 2011)
- Internet dashboards
- Light meters
- Handheld temperature meters
- Clamp-on ammeters
- Data loggers
- Flashlights
- Occupational Safety and Health Administration (OSHA) safety apparel

HAZARDS NOTE: Do not touch or manipulate any system element! Always ask the system engineer or operator to conduct any task you desire. Do not touch electrical elements, always wear safety glasses, and obey all posted safety signs. Make sure all electrical elements are locked out and tagged out prior to touching. This was not originally a sidebar – but I would suggest making it one.

WATER

INTRODUCTION

Water measurement protocols at the Diagnostic Measurement level build on Basic Evaluation measurement protocols, using the same procedures but adding data normalization and possibly submeter readings to identify nonsanitary water use and areas for performance improvement.

Normalization of water use can determine more accurately the effects of water reduction procedures. For standard commercial buildings, sanitary water makes up a significant portion of the facilities water use, so normalizing the water usage for the number of occupants is important to the accuracy of the reduction efforts. If data is not normalized for occupancy, changes in occupancy can skew the effects of any water reduction attempts and mask the effect of the efforts. If a facility has other significant uses of water, such as landscape watering (larger than 10% of the building floor area), large kitchens, or process water uses that are not separately metered, then meters must be installed so those loads can be separated from the sanitary water use and its normalization. See the Advanced Analysis procedures for measurement of these loads.

If users desire more accuracy in the water use reduction measurements and have many types of significant water use, they should use the procedures presented at the Advanced Analysis level.

PERFORMANCE MEASUREMENT PROCEDURE

The Figure 3-4 flowchart indicates the basic procedures for lowering water usage at the Diagnostic Measurement level. Most of the Diagnostic Measurement process is the same as for the Basic Evaluation process with some data normalization added to increase the accuracy of the measurements. The user may also wish to add submeters to improve accuracy.

Expand Performance Measurement Plan

The Diagnostic Measurement performance plan builds on the plan for Basic Evaluation by adding the following criteria:

- Normalization of the water usage data based on the number of occupants.
- Calculations for the normalization of the data.
- A description of the standard measurement format and time interval for the water measurement data. While Basic Evaluation measurements use monthly or annual data, measurements at the Diagnostic Measurement level may use shorter periods or monthly data intervals. For monthly data the normalization is the average number of occupants per day per month.

Collect Building Information

In addition to the basic information about the facility collected at the Basic Evaluation level, normalization data on the daily-average number of occupants per month is needed at the Diagnostic Measurement level.

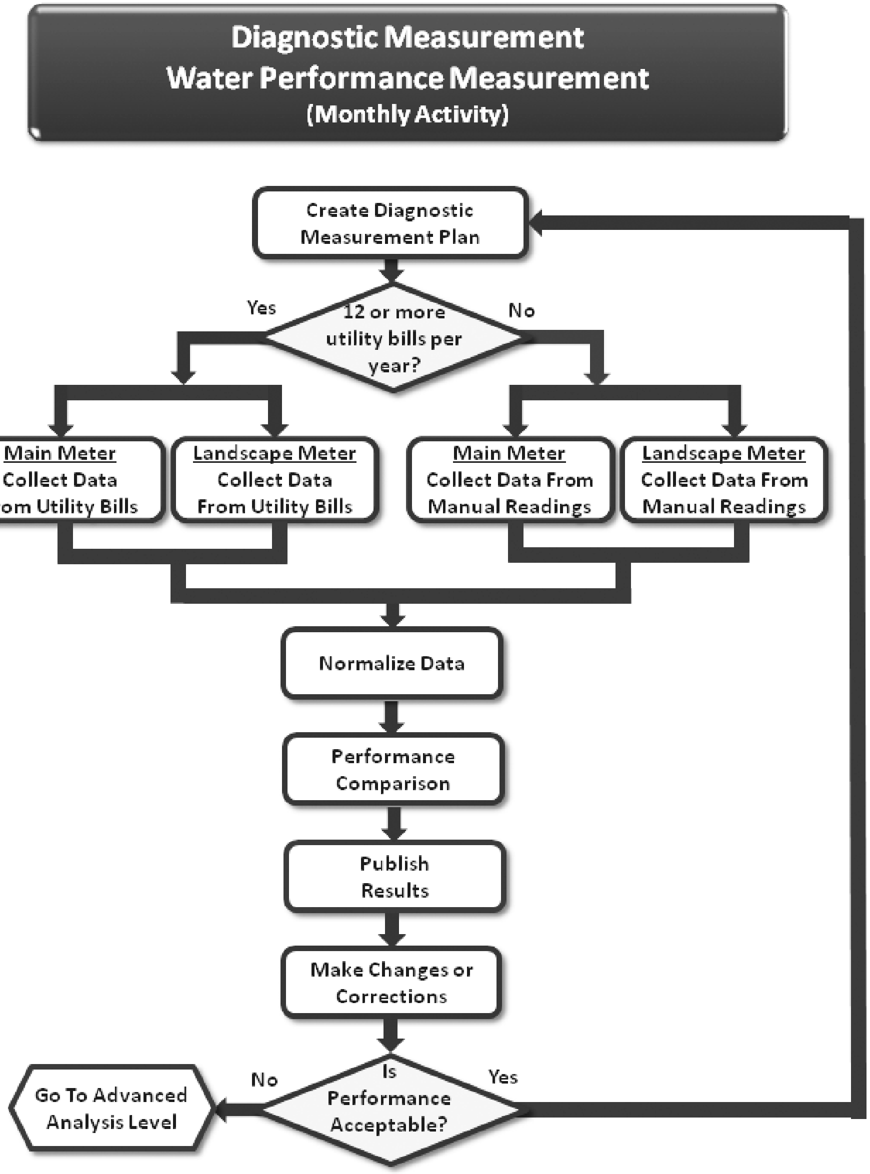


Figure 3-4 Water Diagnostic Measurement Performance Measurement Procedures

Conduct Performance Observation, Measurement, and Analysis

For the Diagnostic Measurement level the measurements are taken from utility or local monthly water meter readings. This data can be obtained from monthly utility water bills or directly from the water meter manually. If taking manual readings, verify the units used at the meter. Many utilities use 748 gallons per meter unit of measure, so verify this amount from your utility or meter manufacturer.

In addition to the meter readings, normalization data (the number of occupants) need to be recorded as the average number of occupants per month. The water use calculations are based on full-time equivalent (FTE) occupants, defined as one person for an eight-hour period per day, distinguished by gender. If the facility also has a quantity of visitors per month, divide the average number of visitors times the average stay per day by eight hours to determine the average number of transient occupants and add that to the normal building occupants.

Input the monthly water use, cost, and number of occupants by gender by week or by month into the Diagnostic Measurement Water Verification Workbook available on the companion CD (see Appendix F for filled in example forms and charts) or other similar comparison worksheet to track use over time.

It is important that the data placed into the main water meter section of the Diagnostic Measurement worksheet primarily represent the sanitary water use. Place all other metered water uses into the landscape water meter section so that the normalization will be correctly displayed. Note that if process loads are separately metered, these will be distinctly accounted for at the Advanced Analysis level; at the Diagnostic Measurement level they are included with the landscape water.

Conduct Performance Comparison (Benchmarking)

To Past Performance

Normalized current performance is compared to normalized past performance through the forms and charts in the Diagnostic Measurement Water Verification Workbook (see Appendix F for filled in example forms and charts), which compares the current and past months' normalized data to the same periods' data for the previous year.

To Baseline Databases

Once past usage is established, use ENERGY STAR or other national databases (see Table 2-3) to rate the existing facility water use to the water use of similar facilities. Record this rating for reference when comparing future results.

To Design Baseline Data

Building water use may be compared to the original design water use by calculating the plumbing fixture estimated flow and adding the predicted landscape water use per month. The calculation method for estimated design data is as follows.

Determine the FTE occupants by gender and calculate the number of daily average visitors. From Appendix F, Table F-2, calculate water flow using the following formulas:

$$\text{(occupants by gender)} \times \text{(fixture flow per use)} \times \text{(number of uses per day)} = \text{gpd (L/day)}$$

$$\text{(occupants by gender)} \times \text{(fixture flow)} \times \text{(number of uses per day)} \times \text{(average time per use)} = \text{gpd (L/day)}$$

$$\text{(number of fixtures)} \times \text{(number of cleaning activities per day)} \times \text{(gallons per cleaning activity)} = \text{gpd (L/day)}$$

Make Corrections or Adjustments

As at the Basic Evaluation level, use the checklist suggestions from Appendix A or other suggestions from water reduction information sources to determine what steps can be taken to reduce water use. Typical suggestions are to lower the water pressure to the minimum required to operate the existing plumbing fixtures on the highest level of the building. Other suggestions include the following:

- Repair all leaks. Use the leak calculation table in Appendix F (Table F-1) to calculate the water use for any leaks found. This number can be used to anticipate the future month's water reductions. Leaks may be more easily identified by checking water meter flow during unoccupied times when landscape watering is not scheduled. If water flow is detected, leaks are present in the system.
- Determine the savings from possible replacement of fixtures with more efficient ones by using the calculations and use tables in Appendix F. This data will allow financial projections as to the water and cost savings for fixture replacement.
- Lower landscape water times and flows to the minimum required for the existing plantings. This can be determined by using the calculation included in the Advanced Analysis description to approximate the minimum required water for the plant types used. Basic soil moisture measurements may be required to determine the minimum water use.

Water usage is normally overlooked by most occupants and operators. Therefore, the most important adjustment to lower water use is to make occupants aware of the amount of water used and to keep them focused on water use reduction.

Remeasure Performance

Once corrections and adjustments are made, remeasure the performance of water usage. This can be done by using the next utility bill or by taking manual meter readings.

Compare New Performance to Past Performance

Compare the new measurements to measurements from the past year's same period to determine if the adjustments or corrections have made a difference in water use characteristics. Be aware that even though the data is normalized for the number of occupants, other variances in schedules, weather, and HVAC load or system conditions may change water usage in buildings. If it is desired to gather additional submetered data or to normalize the data using additional parameters, use the Advanced Analysis procedures.

Report Results

As described for the Basic Evaluation level, reporting the results to both operators and occupants is very important to the success of any water reduction program. It is recommended that the output graphs of the Diagnostic Measurement Water Verification Worksheet (Appendix G, Figure G-1) be reported to all building occupants and operators and to people who are responsible for the financial aspects of the facility. This will allow management to better understand the benefits of the water reduction program.

TOOLS AND AIDS

The Diagnostic Level Water Verification Workbook tool shown in Appendix F and included on the companion CD can be used to assist the user in collecting and analyzing the data and to produce meaningful output information for reporting. To use this tool, simply input the water use and cost data from the periodic utility bills for each month into the appropriate cells in the current utility data page that correlates to the rate structure. Also input the number of occupants into the appropriate cell to provide the data normalization. The user must also input the previous year's monthly data and normalization data into the previous year utility data page. This data automatically produces the water use and cost output charts.

IEQ THERMAL COMFORT

INTRODUCTION

At the Diagnostic Measurement level, physical measurements are taken to diagnose the causes and extent of performance problems identified during Basic Evaluation. Measurements are usually only needed in the areas having problems. Corrections are proposed, and once implemented their effectiveness is tested by repeating the measurements. The people doing the work might be building staff, HVAC contractors, design engineers, or appropriately qualified consultants. The following sections are intended to facilitate effective commissioning (Cx) for thermal comfort.

Documentation should be kept to record the measurement activities planned and undertaken: what, where, when, how, and who. This will allow the measurements and analysis to be tracked by others who may become involved as the process continues.

PERFORMANCE MEASUREMENT PROCEDURE

The Figure 3-5 flowchart outlines the IEQ thermal comfort performance measurement procedure at the Diagnostic Measurement level.

Conduct Performance Observation to Establish Location and Basis of Identified Issues

The first step of the procedure is to review previous plans and data. The plan developed during Basic Evaluation may have identified spaces in the building that need diagnostic measurements. Such spaces can also be identified from the survey results and walk-through inspection observations.

Examine the thermal comfort survey results in detail. The Basic Evaluation occupant survey presents a diagnostic checklist to occupants who expresses dissatisfaction in the top-level thermal comfort scale. The check boxes allow the problems to be identified and their causes hypothesized:

- Is the problem overheating or overcooling, and in which seasons?
- What time of day does the problem occur?
- Is it a Monday or a weekend problem?
- Humidity: too high or low?
- Air movement: too high or low?
- Incoming sun?
- Hot/cold surrounding surfaces?
- Heat from equipment?
- Drafts from windows or vents?
- Thermostat accessibility: who controls; how responsive is it?
- How flexible is the workforce clothing policy?

The survey's anonymity prevents these responses from being associated with particular individuals or workstations, but a response's general location can be narrowed down to floor, wing, façade orientation, and proximity to exterior walls.

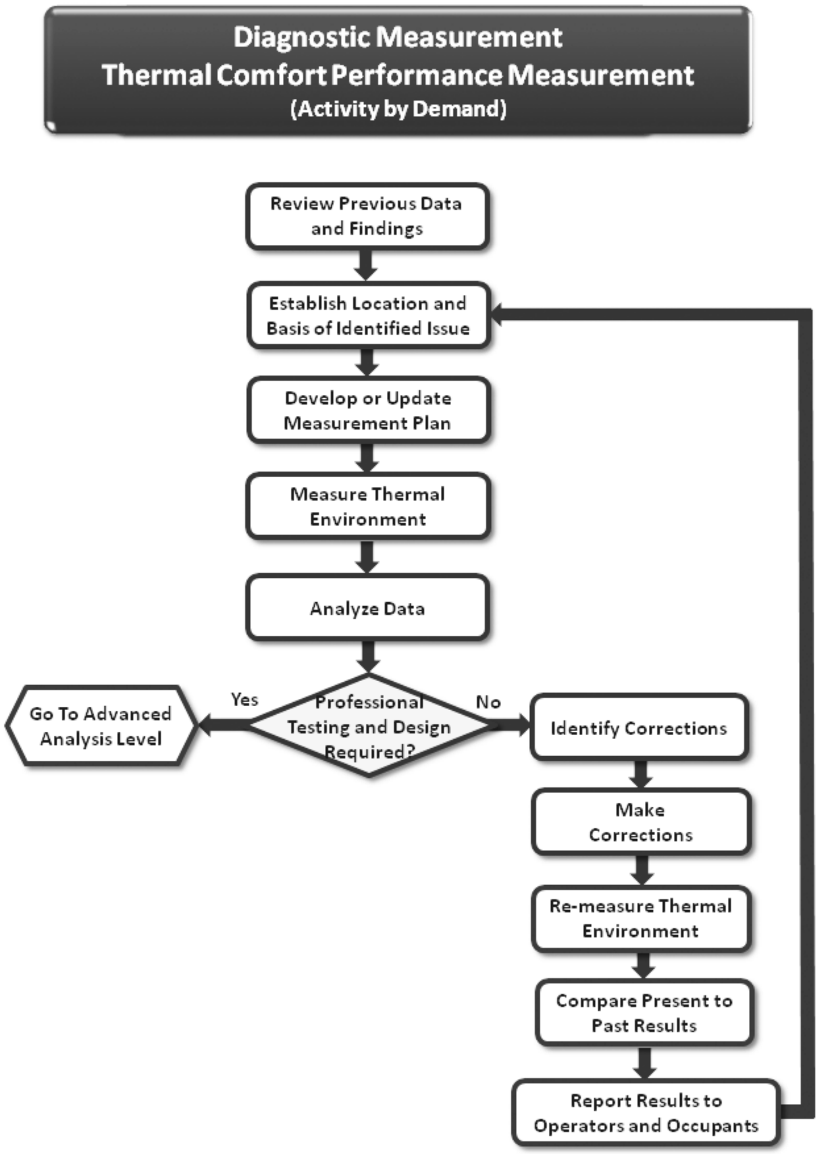


Figure 3-5 Thermal Comfort Diagnostic Measurement Performance Measurement Procedures

In a moderate-sized building, this allows problems to be identified and located within a group of relatively small zones.

The survey also provides space for voluntary, open-ended comments. Commenters frequently discuss the presence of drafts, radiant discomfort near windows, and unresponsive thermostats; their insights are often accurate. As with the diagnostic checklist, the problems described in the comments section can often be narrowed down to a relatively small area of the building.

With this information, it may help to repeat walk-through observations in the identified problem areas to obtain more detail. Observe occupant actions (as at the Basic Evaluation level, but now focus on the problems identified by the survey) such as permanently lowered window shades, cardboard over windows, taped diffusers, modified thermostats, personal heaters and fans, etc. Take photographs of such modifications and document the problems they are addressing. Ask occupants for details concerning why and under what time or climate conditions they took these actions. The problems might then be corrected during the Cx process.

Evaluate occupant behavior in relation to signals sent to facilitate occupant/building operation, if present. Examples of this might be “traffic lights” or “dashboards” pertaining to window opening in mixed-mode buildings. Are the occupants responding to the signals?

Expand Performance Measurement Plan

Prepare a plan for taking physical measurements for identified problems. The measurements will depend on the nature of the performance issues identified in the Basic Evaluation. This information is also obtained from the survey’s diagnostic checklist as described previously and from the walk-through inspection(s).

The plan should identify the persons tasked with carrying out the Diagnostic Measurement tasks: building staff, HVAC contractors, design engineers, and/or appropriately qualified consultants. Measurements may need to be coordinated with the HVAC system operator so that the concurrent state of the system is known and because the testing might require actively controlling the state of the system.

Conduct Performance Measurement and Analysis

Take Physical Measurements

There are two types of physical measurements that provide the data needed for different types of fault detection and performance analysis: spot and time-series. The following describes the typical measurement approaches in each category. Instruments used to make the physical measurements are discussed in Appendix G.

1. **Spot Measurements of Observed Functional Flaws.** Spot measurements should be taken in locations and at times that the survey or visual inspection have identified as problematic. The measurements should identify functional flaws in the building envelope or HVAC system. Examples include high velocities from diffusers reaching into the occupied zone, excessive thermal gradients in the space (vertical or horizontal), uncomfortable radiant temperatures, air temperatures and airflows near glass in summer or winter, and direct solar radiation impinging on occupants in their work spaces.

   Spot measurements are generally taken with handheld or tripod-mounted instruments that can be easily moved to capture effects. The visualization of airflows using media such as smoke, water mist, talcum powder, and soap bubbles is especially useful. Airflow sheets or jets often contain large temperature as well as velocity gradients, both of which affect the comfort of occupants encountering the airflow. These can be seen with an infrared camera viewing a lightweight screen suspended in the airflow. The screen picks up the flow temperature without distorting the flow, and its surface temperature is made visible by the infrared camera.
2. **Logging Time-Series Measurements in Problem Areas of Building.** In addition to instruments that give immediate readout, it is easy and economical to record the thermal environment and HVAC system perfor-

mance over time. Such data logging is useful in detecting patterns in the thermal environment, which may be linked to diagnosing performance of mechanical equipment, control settings, and the building envelope. Time-series data allow intermittent effects to be captured at times when the commissioning authority is not present. Examples include transient processes such as "Monday morning startup," solar gain through fenestration, and cycling of mechanical systems. The data loggers come with computer connections and software for setting measurement time periods and downloading data. Useful time periods range from hours through months. Basic data loggers that record temperature can be obtained for $50 (see Appendix G). Data loggers with additional channels (typically relative humidity, light, and external inputs) cost $100–$200.

- Take temperature and humidity readings in the occupied zone at time intervals anywhere between 30 s and 10 min. This decision depends on the memory capacity of the logger and the length of time expected between data downloads. In general there is little need to measure more frequently than once a minute.
- Note that "temperature" in comfort standards is expressed as *operative temperature* (t_{op}), which is the average of the air temperature and the mean temperatures of all surrounding surfaces (e.g., wall, ceiling, room furniture, equipment). In most indoor spaces, the surface temperatures, or mean radiant temperature, are close to the air temperature, and a thermometer can by itself approximate operative temperature. However, comfort is sometimes affected by exposure to cold or hot surfaces such as windows or equipment, which may be at temperatures that are significantly different from that of the air.

  A globe temperature thermometer can be used to minimize this error and provide a reasonable approximation of operative temperature. It can be fabricated by centering a temperature sensor within a table-tennis ball painted primer grey.

  Alternatively, one can measure the air temperature and radiant surface temperatures independently. True air temperature is measured by shielding the thermometer sensor from radiation using a cylinder of aluminum foil or reflective mylar. The room's surface temperatures are measured using an infrared sensor or camera (see Appendix G). The mean radiant temperature (t_r) can then be calculated for simple room geometries using the ASHRAE Comfort Tool (ASHRAE 1997). The operative temperature is then the average of the shielded air temperature and the mean radiant temperature.
- Humidity (generally relative humidity, or RH) can be measured in fewer locations since it does not vary as much as temperature, and it is also less influential than temperature at determining thermal comfort.
- Air velocity is generally expensive to measure and varies greatly within a space; therefore, anemometers must be carefully positioned to capture a specific flow effect. In some cases one is looking to keep air movement to a minimum, and in others whether there is enough to ensure comfort and good perceived air quality. These affect the required resolution and directionality of the anemometer. Whether a given air velocity is comfortable or not depends on the temperature and on the activity and clothing of the occupants. For example, an

exercise gym may require air movement even at cool temperatures, whereas a lounge at the same temperature would require still air to avoid overcooling the occupants. A naturally ventilated lounge in Hawaii would, however, require air movement because the temperature and humidity are expected to be high. These factors are all accounted for using the elevated air movement criteria in ASHRAE Standard 55 (2010b) and are calculated using the *ASHRAE Thermal Comfort Tool* (1997). This is described in the Advanced Analysis chapter.

Any physical measurements need to be made with awareness of the state of the building's mechanical system. In simple systems this can be done by controlling the thermostat, but more complex systems may involve coordinating with the operator during the testing. If available, it is helpful to obtain BAS trend logs of the system state during the testing period. The merging of BAS measurements with spot- and logged space temperature measurements allows the whole system to be examined. In addition, visual inspection and comparison of Diagnostic Measurement and BAS point values can help identify BAS transducers that are malfunctioning or out of calibration as well as system programming errors.

Analyze Data to Benchmark Performance

Analysis at the Diagnostic Measurement level quantifies compliance with the thermal comfort standard, ASHRAE Standard 55 (2010b), and helps identify flaws in the building system. However, neither a comfortable thermal environment nor a perfectly functioning system necessarily ensure that a building is energy efficient or best practice; this is addressed in the Advanced Analysis chapter.

Hourly values of temperature and humidity from data loggers can be plotted as dots on a psychrometric comfort zone plot, indicating the level of conformance with the standard's comfort requirements. As previously noted, because humidity mixes rapidly indoors and is a weaker driver of comfort than temperature, it may suffice to have one humidity measurement per multiple thermostat zones.

The comfort zone represents conditions that are acceptable to a majority of the occupants in the space and is illustrated in Figure 5.2.1.1 in Standard 55. Because the comfort zone shifts with the clothing level and activity of the occupants, Figure 5.2.1.1 is not absolute but represents comfort for office work at two levels of clothing, winter and summer.

- Figure 3-6 in this chapter is an example of plotting a period of spot or logged temperature and humidity data on the ASHRAE comfort zone chart.
- Near operable windows, a wider range of temperatures is allowed, as determined by the Adaptive Model (see Figure 5.3 in Standard 55). Details are given in the Advanced Analysis chapter.
- The comfort zone warm boundary is extended by increasing air movement, as shown in Figure 5.2.3.2 of Standard 55. (Details are discussed in the Advanced Analysis chapter.)
- The number of hours that exceed the boundaries is the first measure of performance. A simple count of these hours gives a percentage of time dissatisfied. A more comprehensive measure combines this hour count with each hour's temperature differential from the comfort zone bound-

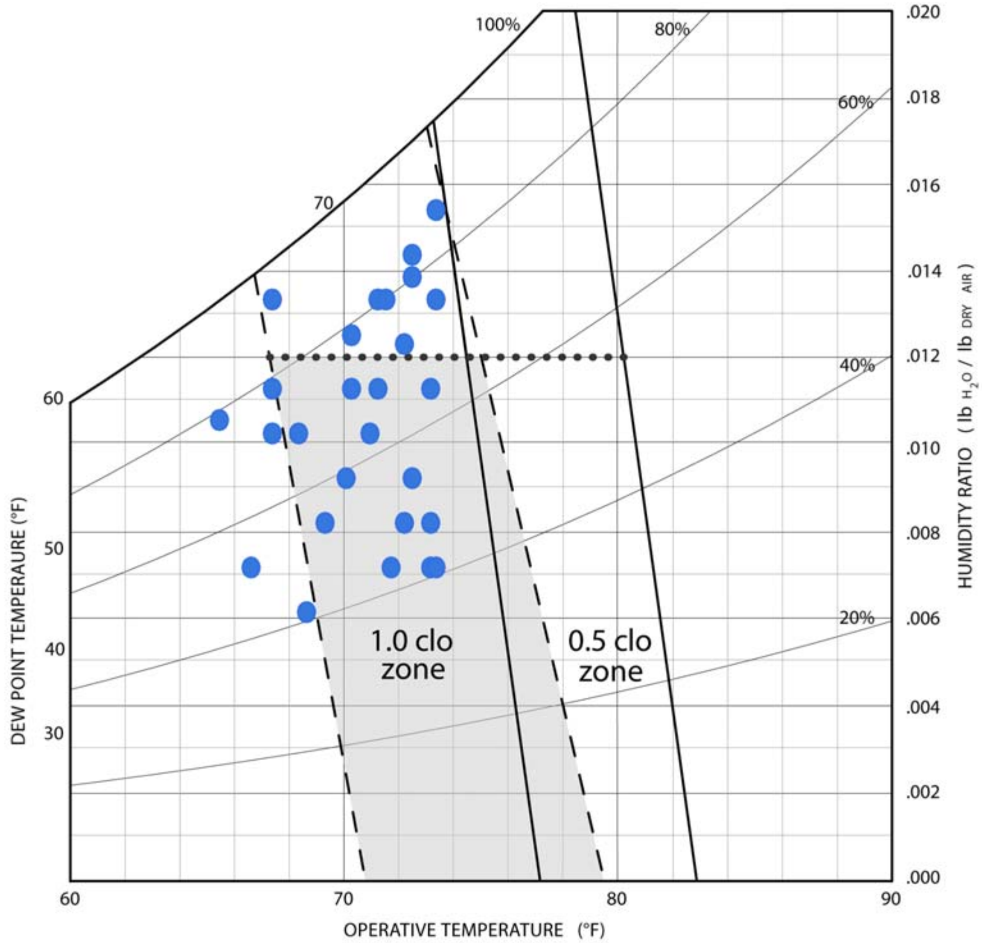


Figure 3-6 Measured Interior Conditions in Relation to ASHRAE Comfort Zone

aries (representing the severity of discomfort). Summing up these temperature differences approximates the total amount of discomfort.

Nonuniformities in temperature are regulated in three ways:

- Maximum vertical air temperature difference caused by thermal stratification
- Range of allowable floor surface temperatures
- Maximum plane radiant temperature asymmetry in any direction (these are likely to be spot measurements, taken at times when asymmetry is most likely or when occupant complaints indicate that it is a problem.)

Table 3-1 defines the limits to nonuniformity in temperature.

Table 3-1 Radiant Temperature Asymmetry Criteria

Vertical Air T Diff	Floor Surface Temperature	Radiant Temperature Asymmetry, K			
		Warm Ceiling	Cool Ceiling	Cool Wall	Warm Wall

Source: ASHRAE (2010a), Appendix B

Table 3-1 Radiant Temperature Asymmetry Criteria

< 3 K	19°C–29°C	< 5 K	< 14 K	< 10 K	< 23 K
< 5°F	66°F–84°F	< 9°F	< 25°F	< 18°F	< 41°F

Source: ASHRAE (2010a), Appendix B

Air movement limits: In Standard 55, air movement is limited to less than 0.15 m/s (30 fpm) in cool conditions. In warm conditions, ambient air speeds up to 0.8 m/s are allowed, with higher levels allowed when groups of occupants have control of air movement in their vicinity (Arens et al. 2009). Because the intentional use of air movement for comfort control is not yet common in today's buildings, the ASHRAE Standard 55 (2010b) air movement provisions are covered in the Advanced Analysis chapter.

The building's performance at meeting these nonuniformity and air-movement criteria is quantified most simply by identifying instances of noncompliance and estimating how commonly they occur. If it is possible to obtain data over longer time periods, one can sum up the number of hours that a building or its spaces are out of compliance.

In addition to measuring compliance with Standard 55, the diagnostic measurements for thermal comfort might also indicate flaws in system operation even when no discomfort results. The flaws might be visible from inspection of the Diagnostic Measurement data themselves or when those data are juxtaposed with system data such as zone thermostat dead bands, supply and return temperatures, and system temperature and flow setpoints. A useful tool for merging logged and BAS data is the *Universal Translator* (PEC 2012) (see the Performance Measurement Procedure subsection of the Energy section in the Advanced Analysis chapter of this Guide for a description of this software).

Make Corrections or Adjustments

When making corrections or adjustments, do some right away (e.g., provide solar control blinds or fix broken ones). But note that some actions, such as resetting thermostat temperatures, may be damaging to overall system efficiency or operation; this may require attention at the Advanced Analysis level. Take care not to make controls adjustments (overrides) that have repercussions during other seasons or in other parts of the building.

Remeasure Performance

Remeasuring performance depends on the situation. It is often obvious when corrections have had an effect. If not, the first remeasure ought to be a follow-up survey of the affected occupants. Sometimes it might not be clear whether the corrections were effective. In such cases, physical measurements might be taken again. Such measurements should be taken consistently, in the same locations and at similar times, so that they allow appropriate comparison of new performance to past performance.

Compare New Performance to Past Performance

After corrections and adjustments are implemented and remeasured, it is important to compare to past performance to verify the improvement level achieved. Account for any changes in season, occupancy, and building operation that might have occurred between the two performance measurement periods. Use similar charts and tables as in the original report so that it is easy to compare and contrast pre-retrofit and post-retrofit performances.

Are the issues resolved? If not, repeat the above steps and refine the correction actions until they are.

Report Results

Prepare a report describing the problems and recommending solutions. The report should include the following:

- Material documented in the Diagnostic Measurement process—what was measured, by whom, and for what reasons.
- Comparisons of spot and logged measurements to ASHRAE Standard 55 (2010b) requirements. Identify any problems observed and how far measured results exceed requirements of the standard.
- Correlations of occupant actions observed during the walk-through inspection to logged service requests and survey results. This leads to identifying physical improvements to building, system, and operation.
- Recommendations for operating changes (e.g., adjusting control sequences) or physical changes to the building envelope or mechanical system (e.g., reglazing, or adjusting or replacing diffusers or radiators).
- After further observation and/or remeasurements, the report should describe how effective it was.
- Suggestions for instituting feedback mechanisms to encourage beneficial occupant behavior or, if already present, for improving the mechanisms' effectiveness.
- Recommendations for specialized investigations that require Advanced Analysis, if any.

TOOLS AND AIDS

Helpful tools and resources include the following:

- *ASHRAE Thermal Comfort Tool* (1997).
- *Universal Translator* (PEC 2012), which is available for free download from www.utonline.org
- ASHRAE Standard 55 (2010b)

IEQ INDOOR AIR QUALITY

INTRODUCTION

This section prescribes measurements related to indoor air quality (IAQ) that should be made and compared to the minimum outdoor air requirements that are listed in the prerequisite documents. If the airflow is below the minimum settings, it is substandard and should be increased to at least the minimum. The measurements required can be made using multiple published methods.

PERFORMANCE MEASUREMENT PROCEDURE

Diagnostic Measurement procedures for IAQ are outlined in the Figure 3-7 flowchart.

Expand Performance Measurement Plan

Prepare a plan for observing and surveying locations deduced from the survey results. Determine if there are any IAQ complaints from the areas where the sur-

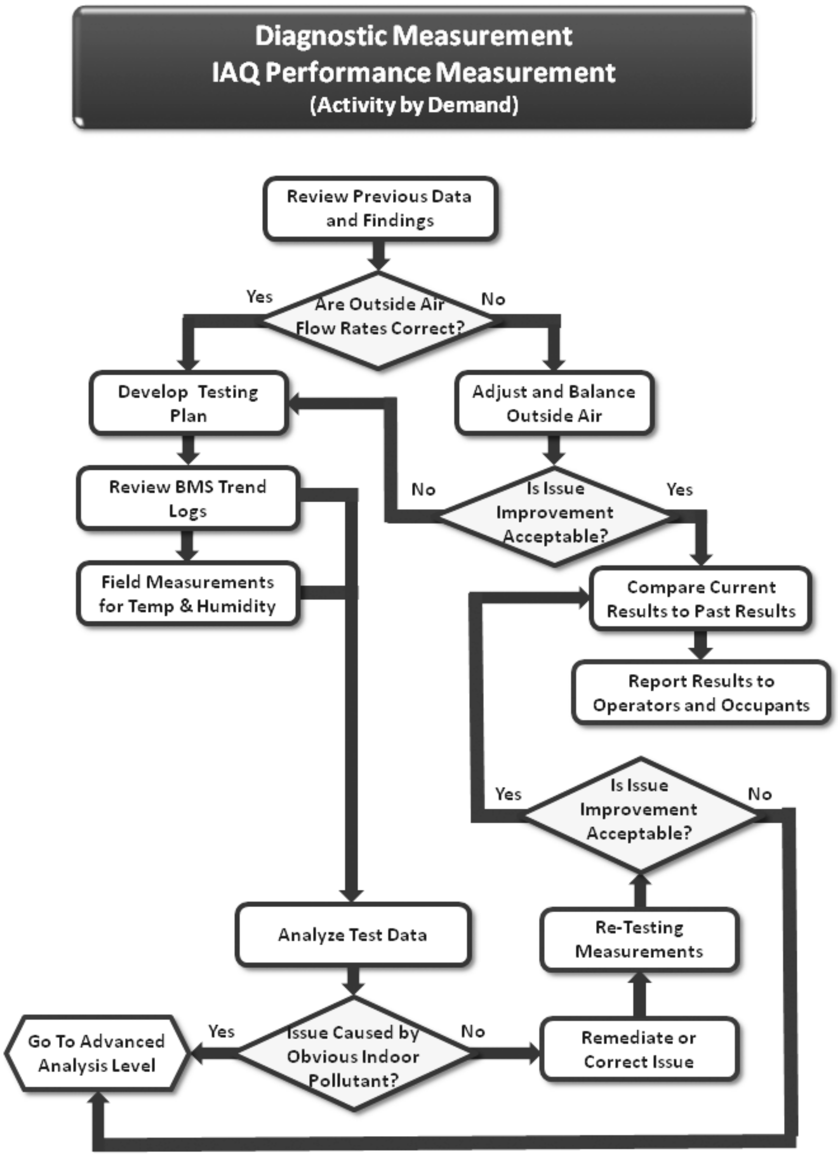


Figure 3-7 Indoor Air Quality Diagnostic Measurement Performance Measurement Procedures

vey indicates that there may be problems. The plan should identify the person(s) to conduct the investigative tasks: building staff, HVAC contractors, or design engineers.

Collect Building Information

The building data need to be gathered only where problem areas have been identified so as to establish the locations and causes of the problems to be addressed.

Do not begin any measurement program for remedying IAQ problems in this phase of the process. If IAQ problems are confirmed and cannot be remedied by simple measures such as replacing molded materials with new materials, go to the Advanced Analysis level and retain an expert to investigate.

Conduct Performance Comparison (Benchmarking)

The benchmark for IAQ is that there should be no apparent problems diagnosed in the previous steps. If there are no problems, then the building can be benchmarked against ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2010c), and/or the building design specifications for an indicator of adequacy of steps to prevent IAQ problems. This benchmarking primarily involves gathering the data needed to calculate the zone-level ventilation required for complying with the standard, as specified in the multi-zone ventilation distribution spreadsheet MZ Calc, which is available on the CD that accompanies *62.1-2010 User's Manual* (ASHRAE 2010d).

Conduct Performance Observation, Measurement, and Analysis

Ventilation Measurement

Measure ventilation for each ventilation system.

1. If the building has a BAS, log the outdoor airflow with the BAS and compare to setpoints to ensure that the minimum is maintained at all times that the space is to be occupied.
2. If there is no BAS, calibrate the outdoor airflow intake (damper) annually and record the measurements (within ±10%). These measurements should be made using standard protocols such as those in ASHRAE Standard 111 (2008b) and information in Chapter 36 of *ASHRAE Handbook—Fundamentals* (2009c).
3. For systems <2000 cfm supply air, measure outdoor airflow annually and adjust system settings to provide at least the minimum outdoor airflows. Measure and record the final airflows after adjusting using calibrated instruments and methods from ASHRAE Standard 111 and information in Chapter 36 of *ASHRAE Handbook—Fundamentals*.
4. Calibrate ventilation airflow sensors annually (within ±10%).
5. Calibrate other ventilation-related sensors annually.
6. Test demand-control sequences annually.

Humidity Measurement

Measure room humidity under nonheating conditions. It is recommended that representative spaces be sampled per nonheating month to ensure that room RH < 65%. These measurements do not need to be made during the heating season because in most cases the relative humidity will be low. These measurements also do not need to be made in rooms that are specially constructed with surfaces and drains designed to handle direct moisture such as shower rooms, dishwashing rooms, commercial kitchens, indoor swimming pools, etc.

Measure Exhaust Systems

Check the toilet exhaust airflow direction in restrooms annually by ensuring that air flows into the toilets and not out of the toilets using any reliable air directional indicator.

For any other exhaust systems, measure at appropriate accuracy/frequency.

Filters that are not Changed on Calendar Schedule Basis

Measure pressure drop on particle filters and change at the pressure specified in the building operation and maintenance (O&M) manual. Chemically measure adsorption filters and change when media is no longer effective.

Make Corrections or Adjustments

Performance improvement in IAQ will consist of incorporating new technologies and practices in the building maintenance and operations procedures. Examples of improvements in IAQ that typically are not in building O&M plans or incorporated into building systems include the following:

- Annual cooling system coil cleaning.
- Particle filter upgrades. (Advances in filtration media and products provide opportunities to improve IAQ with small increases in costs. For example, roll media type filters can be replaced with pleated box filters that have a Minimum Efficiency Reporting Value (MERV) rating. MERV 6 filters can be upgraded to MERV 8, MERV 11, or MERV 13. However, note that these filters add pressure drop and may lower airflow rates.)
- Condenser water cleaning. (New technologies are available to improve the cleanliness of condenser water.)
- Evaporator coil and drain pan cleaning.
- Fan-powered box reheat coil performance enhancement by cleaning and/or better filtration.
- Filtering ozone from outdoor air in nonattainment areas by applying currently available air-cleaning technology.

Remeasure Performance

If ventilation is insufficient or if humidity is not properly controlled, then the HVAC system performance should be measured after corrections are made.

Compare New Performance to Past Performance

Compare the new performance to the previous performance to make sure that corrections had the desired effect.

Report Results

Ideally, one should report that no IAQ problems are observed, that the ventilation system provides outdoor air consistent with the requirements of the latest edition of ASHRAE Standard 62.1 (2010c), and that the humidity is controlled per ASHRAE Standard 62.1 requirements. If problems are reported, a gap analysis should be conducted and a plan developed to remedy the problems.

TOOLS AND AIDS

Air measurement tools include those used by test and balance (TAB) firms (e.g., pitot tubes, anemometers, velocity grids, and airflow hoods). An accurate humidity measurement instrument is also required for these basic measurements.

Aids include the latest edition of ASHRAE Standard 62.1 (2010c), TAB reports for the HVAC system, and mechanical drawings. The ASHRAE multizone ventilation distribution spreadsheet MZ Calc, which is available on the CD that accompanies *62.1-2010 User's Manual* (ASHRAE 2010d), can assist in the calculation of the airflow required at the outdoor air intake for each HVAC system. Aids also include *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* (ASHRAE 2009a).

IEQ LIGHTING/DAYLIGHTING

INTRODUCTION

The Diagnostic Measurement level comes into play for IEQ lighting/daylighting for one of two reasons: either some lighting issues uncovered during Basic Evaluation could not be resolved through a simple correction or it has been determined that it is advisable to measure the light levels in one or more spaces. For example, it might be deemed important to measure light levels in spaces where the visual tasks are particularly critical, such as at an inspection station. In either case, this level involves gathering additional building data, performing a lighting audit, and taking lighting measurements. These activities can be conducted by properly trained in-house personnel or may require the use of an outside professional with lighting/daylighting expertise.

PERFORMANCE MEASUREMENT PROCEDURE

The IEQ lighting/daylighting Diagnostic Measurement procedures, illustrated in the Figure 3-8 flowchart, are discussed in detail in this section. These steps are not necessarily sequential but are presented here in an order that will assist the user in determining if there are lighting quality issues and how to proceed from there.

Expand Performance Measurement Plan

Using the results of the Basic Evaluation, determine which spaces need to have point-by-point illuminance measurements. The expanded plan should identify who is to be involved in carrying out the Diagnostic Measurement steps; typically building staff, outside contractors, design engineers, and/or appropriately qualified consultants would be considered likely candidates.

Collect Building Information

There are two types of building data that need to be collected for each space that has been identified as needing illuminance (and/or luminance) measurements: space details and a lighting audit.

Space Details

Basic information about the spaces needs to be collected and recorded to use during the measurement and comparison process. This process can be facilitated by using the Space Details Worksheet in Appendix I.

The basic information needed (and to be listed on the Space Details Worksheet) for each space or room under consideration is the following:

- Building identifier.
- Space identifier.
- Space type (e.g., office—enclosed). Note that the electronic version of the Space Details Worksheet has a drop-down menu providing a list from which to select.
- Area, ft^2 (m^2).
- Height, ft (m).

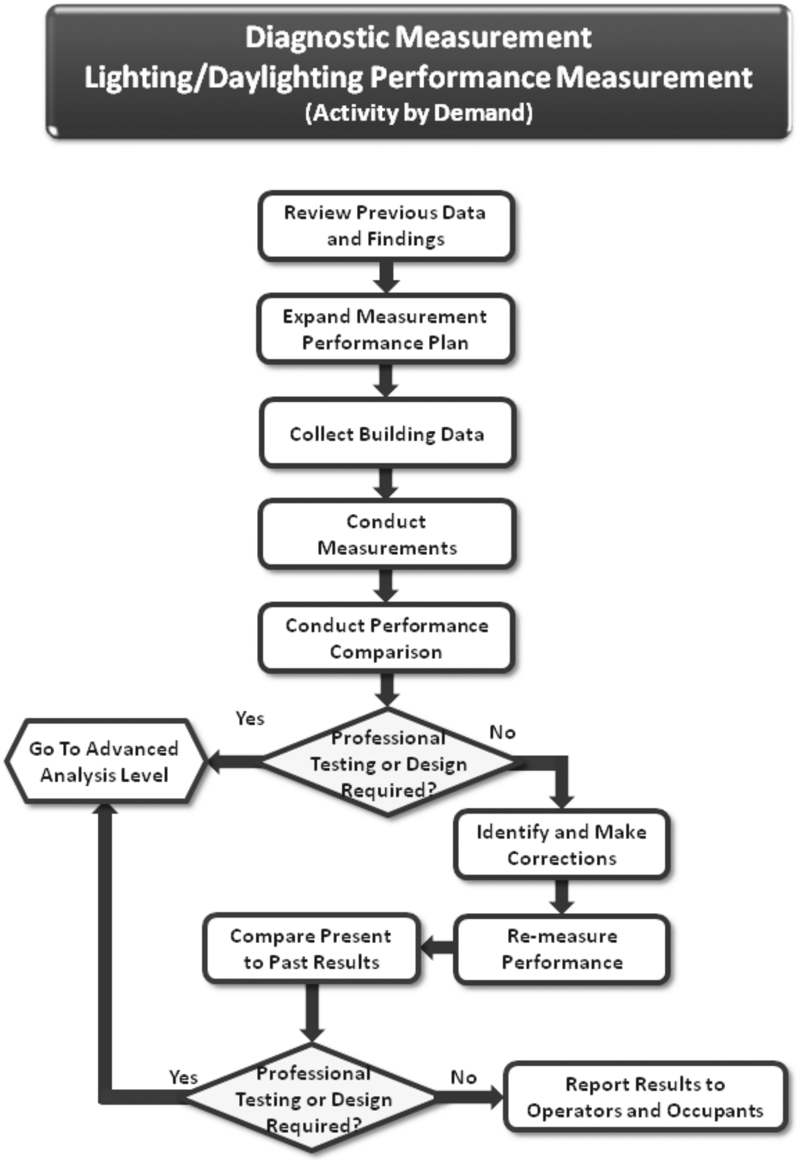


Figure 3-8 Lighting/Daylighting Diagnostic Measurement Performance Measurement Procedures

- Reflectances of room surfaces (including the ceiling, walls, floor, and any partitions in the space)—i.e., what percentage of the light that strikes this surface is then reflected off of it; if this is unknown, it will still be beneficial to label each surface as dark, medium, or light.
- Window-to-wall ratios in rooms with daylighting (the percentage of wall area taken up with window area).
- Notations about known issues with the lighting and lighting controls—answering yes here indicates that at least one issue was found in this space during the Basic Evaluation.

Lighting Audit

After the space details, we need to know exactly what lighting equipment is in each space. The forms shown in Appendix I and included on the companion CD can be used for this purpose. This spreadsheet may be used to list, for each space, the following:

- Type of luminaires installed (by type ID and description)
- Number of luminaires installed (by type ID and description)
- Input watts (not just lamp watts)
- Annual hours of operation

These data normally need to be obtained by visual examination of the spaces by someone with lighting expertise; depending on existing space drawings, which may or may not have been kept current, will frequently result in errors.

The form shown in Appendix I and included on the companion CD also includes a section to document this information for any proposed changes to the lighting system.

Conduct Performance Observation, Measurement, and Analysis

For each specified space, one or both of the following measurement sets should be acquired (see Appendix I for a discussion of equipment typically used for these measurements):

- Point-by-point illuminance measurements should be made on the work planes of all specified spaces. The height of this horizontal work plane will generally be 2.5 ft (0.76 m) off the floor, but other heights may be used depending on the location of the primary visual task. Measurement points should typically be spaced 2 ft (0.6 m) apart, subject to the perceived uniformity of the lighting/daylighting in the space. A form that may be used to record these measurements is shown Appendix I and included on the companion CD. Depending on the issues brought up during the Basic Evaluation and the typical activities in the space, the plane of measurements might also include one or more vertical or sloped surfaces.
- In significantly fewer situations, point-by-point luminance measurements may be required on one or more room surfaces where issues of luminance ratios or glare are important. A form that may be used to record these measurements is shown in Appendix I and included on the companion CD. This process should be considered when survey results, occupant interviews, and/or maintenance records indicate occupants have issues of visual fatigue, such as headaches from eye strain.

Conduct Performance Comparison (Benchmarking)

The results of the illuminance measurements can be compared against the lighting recommendations found in *The Lighting Handbook* (IES 2011). Chapter 22 of this handbook contains the lighting recommendations for common applications, while Chapters 21 and 23 through 37 contain the lighting recommendations for specific applications such as lighting for offices and lighting for manufacturing. Each of these chapters includes an extensive table providing lighting recommendations that typically include the following:

- A description of the application and/or task.

- Recommended horizontal illuminance based on the majority of regular occupants being within one of three age ranges:
  - under 25,
  - 25 to 65, and
  - over 65.
- The gauge of this horizontal illuminance (i.e., whether it is a recommended minimum, average or maximum).
- Recommended vertical illuminance based on the three age ranges above.
- The gauge of this vertical illuminance.
- A uniformity recommendation, typically consisting of one of the following:
  - the ratio of the maximum to average illuminance,
  - the ratio of the average to minimum illuminance, or
  - the ratio of the maximum to minimum illuminance.
- A recommendation of whether this application is generally a good candidate for integrating daylighting with electric lighting to meet the recommended illuminance.
- An indication of how likely it is that this application or task will be subject to the glare of veiling reflections.
- An indication of where the recommended illuminances should be met relative to:
  - the entire room or
  - the task area alone.

If in-house personnel have been making these measurements, then the comparison conducted should be evaluated to determine if the use of either outside testing or outside design services is needed. This might be the result of either not being able to interpret the results properly or not knowing how the lighting needs to be changed to correct the problem. If the decision to use outside services is made, proceed to the IEQ Lighting/Daylighting section of the Advanced Analysis chapter of this Guide.

Make Corrections or Adjustments

In some cases it may be possible for in-house personal to make the adjustments needed by adding or moving luminaires. However, in most situations, when lighting levels or uniformities fall short of or significantly exceed recommended levels, it is probably best to proceed to the IEQ Lighting/Daylighting section of the Advanced Analysis chapter of this Guide and involve a design professional with lighting/daylighting experience.

Remeasure Performance

After the recommended design solutions have been implemented, determine if these have solved or at least partially mitigated the issues. This process might include remeasuring all or part of the illuminance and luminance measurements and modifying the lighting equipment inventory sheet accordingly.

Compare New Performance to Past Performance

Regarding light levels and uniformity, the comparison is not against the previous measurements but instead addresses the question “Have the changes brought

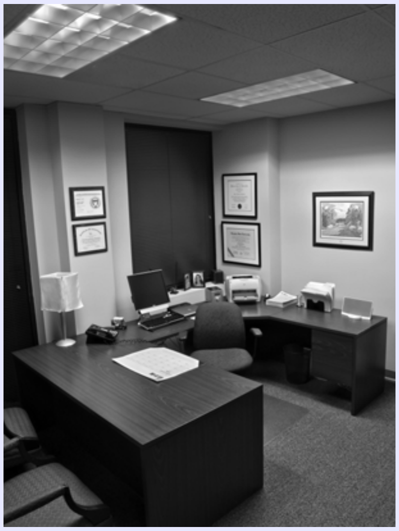
Example of a Lighting Retrofit

Sidebar should go in Lighting section of Chapter 3.

In this example we show that a lighting retrofit can generate both energy savings and improved visual performance.

If we assume an existing facility with a 4-lamp, 2×4, T12 luminaire every 64 ft^2 (5.9 m^2) using 188 lumens/fixture for 2600 operating hours per year, this will result in $0.15/kWh consumption charges that can be reduced about 82% by switching to a 2-lamp, 2×4, T5 luminaire every 80 ft^2 (7.4 m^2) using 59 lumens/fixture and an occupancy sensor to cut the operating hours by about 30%. When the energy savings are combined with reduced lamp replacement costs and reduced HVAC costs, the payback for this retrofit is just a little over two years.

And with the new system the visual environment is improved by reducing the "cave effect" and opening up the space, as illustrated in the figures below.



Before (Left) and After (Right) Retrofit

Reproduced by permission of Acuity Brands Lighting, Inc.

the light levels and/or uniformities in line with the recommendations in *The Lighting Handbook*?"

Again, this is a good opportunity to evaluate the advisability of bringing in outside consulting services if new results indicate that the problems have not been corrected as expected. For example, light levels may have been brought up to the recommended levels, but another survey of the occupants indicates there is still dissatisfaction. If this is the case, proceed to the IEQ Lighting/Daylighting section of the Advanced Analysis chapter of this Guide.

Report Results

In general it is advised that the results of this process be reported to management, building operators, and the occupants. This will help reinforce the effect lighting issues potentially have on company performance and the importance the company associates with them. In general, such a report should include the following:

- Initial results of measurements.
- Corrective actions taken.
- Follow-up measurement results.
- Any company procedures changed as a result of this effort.
- Any company procedures that need to be reinforced in order to reduce or eliminate a reoccurrence of the lighting issues.

TOOLS AND AIDS

Helpful tools and resources for IEQ Lighting/Daylighting at the Diagnostic Measurement level include the information and forms in Appendix I:

- Space Details Form
- Lighting Inventory Worksheet
- Illuminance Measurements Form
- Luminance Measurements Form
- Recommended Illuminance Levels in Some Typical Space Types
- Lighting Measurement Instrumentation

IEQ ACOUSTICS

INTRODUCTION

At the Diagnostic Measurement level, physical measurements for acoustics are taken to diagnose the extent of dissatisfaction identified at the Basic Evaluation level. Either the issue identified could not be solved through simple corrective actions, or additional measurements are recommended. Occupant dissatisfaction related to background noise and intruding noise typically requires additional sound level measurements. Issues related to speech intelligibility may require additional calculations to evaluate the reverberation time of the space. If the building operator suspects that architectural or mechanical design and remediation are required, the operator should consider proceeding directly to the IEQ Acoustics section of the Advanced Analysis chapter of this Guide.

The persons doing the work might be building staff, commissioning authorities, HVAC contractors, design engineers, or appropriately qualified consultants. Building operators and owners without personnel skilled in doing sound level measurements should proceed to Advanced Analysis and seek outside professional services.

PERFORMANCE MEASUREMENT PROCEDURE

The Diagnostic Measurement procedure for IEQ acoustics is illustrated in the Figure 3-9 flowchart, and each step is discussed in greater detail in the text.

Expand Performance Measurement Plan

Measurements should be performed at locations where the Basic Evaluation survey identified occupant dissatisfaction with the acoustic environment. Spaces of significant importance are where occupants indicated that the acoustic quality in their work spaces interferes with their ability to complete their work satisfactorily. Most issues relating to occupant dissatisfaction require sound level measurements. Additional calculations of reverberation time are also advised where

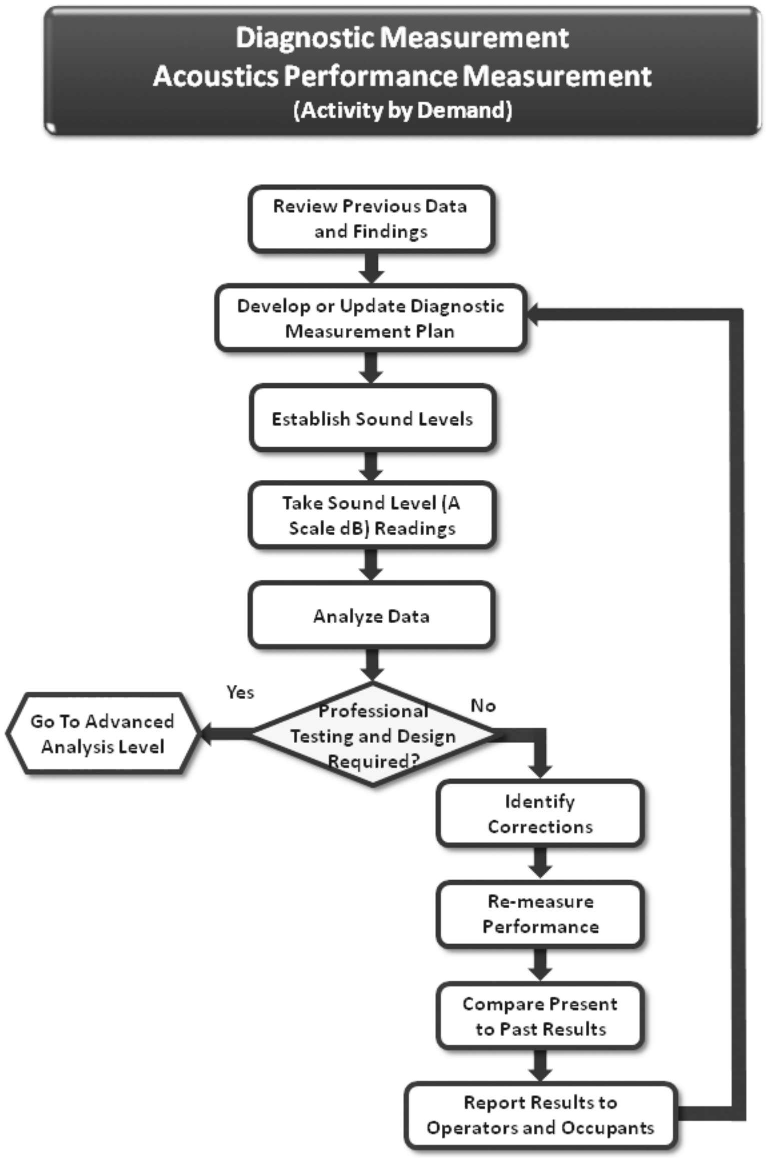


Figure 3-9 Acoustics Diagnostic Measurement Performance Measurement Procedures

speech communication is an issue, for example in classrooms and conference rooms.

Collect Building Information

Building data need to be gathered only for those occupied spaces where acoustic issues have been identified. The basic information needed can be recorded in the Diagnostic Level Acoustics Verification Worksheet shown in Appendix J and included on the companion CD and consists of the following:

- Room number
- Wing/HVAC zone
- Number of occupants

- Room type/activity (Note that the electronic version of the Diagnostic Level Acoustics Verification Worksheet has a drop-down menu providing a list from which to select.)

If speech intelligibility is an issue, such as in classrooms or conference rooms, the following additional information should be recorded in the Reverberation Time (T_{60}) Calculation Worksheet (one sheet per room) shown in Appendix J and included on the companion CD:

- Room length
- Room width
- Room ceiling height
- Description of the room surface materials (Note that the electronic version of the Reverberation Time (T_{60}) Calculation Worksheet has a drop-down menu providing a list from which to select.)

Conduct Performance Observations, Measurement, and Analysis

Measure Sound Levels

Measure the A-weighed equivalent sound levels (L_{eq} in dB(A)) in the spaces identified by the Basic Evaluation occupant survey. Measurements should be made using instrumentation equivalent to an integrating sound level meter equipped with an omnidirectional condenser microphone. Specifications for sound level meters and an example worksheet for recording sound measurements are shown in Appendix J and included on the companion CD. Table 3-2 illustrates the results of such measurements for an office building with a variety of space functions. Examples are provided in Appendix J.

A handheld Type 1 portable acoustic calibrator should be used to check the sound level meter calibration before and after each measurement session. Both the meter (including the microphone) and the portable acoustic calibrator should be certified to have been calibrated by an independent testing agency that is traceable to National Institute of Standards and Technology (NIST). The calibration date for the measurement system should not be more than one year prior to the test date.

The acoustic measurements should, if possible, be conducted with the room vacated by its normal occupants. If this is not possible, the report should indicate the occupancy of the room and a general description of what the occupants were doing during the measurements. In addition, all non-HVAC-related sound-producing equipment (computers, radios, etc.) should be turned off during the measurements.

Background noise is usually controlled by the HVAC equipment serving the space. The operating condition of the HVAC equipment or system serving the room during the measurement should be determined and reported. If possible, the

Table 3-2 Diagnostic Measurement Worksheet Example

Diagnostic Measurement Worksheet - IEQ Acoustics	
Office Building Example	
Name of Building:	XYZ Supply Company
Address:	123 Central Blvd.

Table 3-2 Diagnostic Measurement Worksheet Example

City/State/Zip: San Diego, CA
Date: 2/2/2012
Data collected by: Jason Smith

Room Number	Wing/Zone	Number of occupants	Room Type/ Activity	Criteria (Benchmarks) Leq dB(A) Ideal	Leq dB(A) Max.	T_{60} (secs)	Measured Leq dB(A)	Estimated T_{60} (secs)	Comments
2nd floor	North-East	32	Open-plan office	45	50	< 0.8	40 - 50	0.6	East side window partition height only day-lighting. Traffic audible from outside East perimeter
201	North-East	15 max	Conference room	35	45	< 0.6	46	0.3	This room has FP-V that supplies Rm 20 203. Too noisy in aft
203	North-East	15 max	Conference room	35	45	< 0.6	35	0.3	
205	North-East	15 max	Conference room	35	45	< 0.6	38	0.3	Noise intrusion from occurs often.
207	North-East	25 max	Video-Teleconference room	30	35	< 0.6	32	0.4	Regular video confe with branch offi
202	North-East	1	Private office	35	45	< 0.6	32	-	
204	North-East	1	Private office	35	45	< 0.6	38	-	
206	North-East	1	Private office	35	45	< 0.6	36	-	
208	North-East	1	HR meeting room	35	45	< 0.6	35	-	Privacy is a conc
Lobby	Ground floor	n/a	Lobby	45	55	n/a	48	0.7	
Cafeteria	Ground floor	100	Large meeting room, with speech amplification	35	45	< 0.7	47	1.5	Cafeteria is often use employee meetings. too reverberant. C improve by removi making machine (too and add a little so absorption in the c

measurements should be conducted with the system operating at full capacity (e.g., during maximum cooling for a variable-air-volume system). Measurements at two or three different operating conditions (e.g., maximum cooling, maximum heating, full economizer, etc.) are strongly encouraged but not required. In all cases the HVAC system should be operating at a known steady-state condition during the measurements.

If intruding noise from outdoor sources (e.g., aircraft, street traffic, lawn mowers, etc.) is of concern, then testing should be scheduled during time periods when these sounds are at a maximum. If widows are designed to be opened for ventilation, then measurements should be performed with the windows both open and closed. If intruding noise is a normal occurrence and a significant source of occupant dissatisfaction, then measurements should be made and comments should be recorded on the nature of the intruding noise.

Indoor background noise should be measured at any normally occupied location and specifically in the area where the occupant's head would typically be located (e.g., near the seated position in front of a desk in a private office). If desired, more than one measurement point may be measured. For large open areas, several measurements should be obtained, making sure that the noisiest locations are included. At each measurement point, record the time-averaged A-weighted sound pressure level (L_{eq}). The minimum duration of each measurement should be 30 s. The sound level meter operator should take special care to avoid taking any acoustic measurements when transient sounds (e.g., people talking, doors closing, etc.) are present.

Acoustic measurements should be made within a measurement volume that is defined as any locations at least 1 m from any room boundary (wall, floor, or ceiling) but not more than 2 m above the floor. The sound level meter should be positioned so that the microphone is never closer than 0.5 m from any object in the room (e.g., furniture). In small or narrow rooms, of less than 2.5 m in width, the measurement volume may be relaxed to any location at least 0.5 m from room boundaries.

The measurement microphone may be either handheld or mounted on a tripod. Because a handheld meter makes it possible to spatially average the sound by moving the meter during the measurement, the results tend to provide a sound level more representative of the room average sound level compared to the results from a motionless meter, especially if the background noise spectrum contains tones. However, caution must be exercised when moving a handheld meter due to the potential for noise generated by the movement of the person holding the meter, such as footsteps.

There is no substitute for simply using your ears during the noise measurements, particularly in describing any unique character of the sound. If there is a tonal quality to the sound or if the sound is attention getting, such as speech or music, this should be noted. Likewise, if the sound amplitude is time varying, pulsating, or event based (aircraft flyovers, for example), this should also be noted on the worksheet. Where possible, the source of the noise should be identified. Temporarily turning on and off equipment and repeating the measurement is a useful technique for diagnosing the source of the background noise. It could be found to be the HVAC system or office equipment in an adjacent room, for example. Observations regarding the source of the noise and the character of the sound should be noted in the measurements worksheet.

Evaluate Room Reverberation Time

In those spaces where occupants are dissatisfied with echoes or poor speech communication, it will generally be necessary to evaluate room reverberation time (T_{60}). Typical spaces where T_{60} is critical are classrooms, lecture halls, conference rooms, and large areas that require public announcements. The measurement of room reverberation requires significantly more complex equipment than a sound level meter and is best performed by someone skilled in acoustic measurements. However, a simple diagnostic assessment of the space is possible by calculation of the reverberation time based on the room volume, surface finishes, and room furnishings. A simple estimate of the reverberation time may be all that is needed to decide whether corrective action is required.

A calculation method for room reverberation is provided in Appendix J. First, an estimate of the room volume is made by approximating the space as a rectangular room of roughly the same volume. Both generic (drywall, concrete, etc.) and specific (ceiling tile, carpet, etc.) sound absorption data for the room finishes are used in the calculation. Sound absorption data are provided for typical floor, wall, and ceiling constructions via drop-down menus in the electronic version of the worksheet included on the accompanying CD. Advanced users can enter their own absorption coefficient data if available. The last step is to account for any sound absorption due to furnishings (chairs, drapery, etc.) or commercial sound-absorptive elements (clouds, baffles, etc.) that are not part of the basic room surfaces. Finally, the sound absorption of the occupants themselves should also be included via the drop-down menu on the electronic version of the worksheet, unless the T_{60} requirements are specific to unoccupied spaces, such as classrooms. The resulting calculations can be transferred to the Diagnostic Worksheet for analysis.

The reverberation room calculation should be conducted in the five octave bands from 250 to 4000 Hz. The calculated reverberation time in all octave bands should be compared with the T_{60} criteria for the room, with the exception of classrooms, where the 500 to 2000 Hz band is specified. Where speech intelligibility is of concern, the 500 to 1000 Hz frequency bands are most critical.

Simplified Evaluation of Speech Privacy

Sidebar should go in Measurement, Analysis section of Acoustics in Chapter 3.

Although acoustic privacy is the number-one complaint in office spaces, it is seldom evaluated in the field because current ASTM International test measurement methods can only be conducted by experienced professionals with specialized equipment. Alternative method for screening speech privacy performance that are easy to understand and sufficiently accurate to make simple corrections to the interior design factors. A field-test method based on A-weighted sound level measurements, together with a simple measurement of the noise reduction between work spaces, can generally be used as a diagnostic measurement; details are provided in Appendix J. Although this method has not yet received consensus approval by a recognized standardization organization, it is presented here because there is a critical need for a simplified measurement of speech privacy and because recent research suggests that the method may satisfy the need for such a simplified field-test method.

Conduct Performance Comparison (Benchmarking)

Measurements at the Diagnostic Measurement level should be compared with the recommended and maximum measurements provided in Table 3-3. The criteria are based on the specific use of the space. A range of criteria are provided, with the lowest A-weighted sound level representing a recommended acoustic environment and the highest value representing the level above which further corrective actions are required. Note that the T_{60} criteria apply only to those spaces that require good speech communication. If the calculated T_{60} exceeds the criteria in rooms where good speech communication is critical, further corrective action is required.

Do the measurement levels correspond with the areas of occupant dissatisfaction? Can these levels be related to HVAC noise? If so, what operating conditions create the noise? Likewise for outside noise intrusion, can the measured levels be correlated with periods of high traffic noise or aircraft flyovers?

Make Corrections or Adjustments

If the results of the Diagnostic Measurement indicate that corrective action is required, the following steps are recommended:

- Identify the source or root cause of the dissatisfaction.
- Identify mitigation options and estimate the cost and effectiveness of each.
- Implement the best options.

HVAC equipment noise is sometimes related to the system maintenance or operating conditions. Issues related to equipment noise can usually be resolved by the building operator and maintenance staff. Otherwise the noise may be related to the building's mechanical design, including the equipment and the air distribution system. Issues related to mechanical design typically require Advanced Analysis diagnostics.

Noise intrusion from outside or adjacent spaces may also be a significant sources of dissatisfaction. Noise intrusion from the outside can be related to the building orientation to outside noise sources, ventilation ducts, windows, and other fenestrations. Interior noise intrusion is usually a symptom of inadequate sound isolation between rooms. Noise intrusion from adjacent spaces is related to architectural details, and Advanced Analysis evaluation is recommended.

If T_{60} calculations suggest that the room reverberation is a problem and if corrective actions are extensive, then the services of an acoustical consultant are advised.

Remeasure Performance

If corrective actions were taken, follow-up sound measurements should be repeated using the procedures discussed above.

Compare New Performance to Past Performance

Have the corrective actions made a difference? Note that a 3 dB(A) reduction is barely perceptible, although in terms of speech privacy it could be significant; a 5 dB(A) noise reduction is noticeable; and a 10 dB(A) reduction in noise will be perceived as half as loud. Compare follow-up measurements at the Diagnostic Measurement level with initial measurements and with Table 3-3 levels—the results should fall within the range of levels in this table for the room use.

Report Results

The Measurement Test Report should include the following:

- Facility location

Table 3-3 Recommended A-Weighted Equivalent Sound Criteria for Diagnostic Measurements

Room Type/Application		Level 1—Basic Recommended L_{eq}, dB(A)	Level 1—Basic Maximum L_{eq}, dB(A)
Rooms with intrusion from outdoor noise sources	Traffic noise and aircraft flyovers	45	55
Apartments and condominiums	Living areas	35	45
	Bathrooms, kitchens, utility rooms	40	50
Hotels/motels	Individual rooms or suites	35	45
	Meeting/banquet rooms	35	45
	Corridors and lobbies	45	55
	Service/support areas	45	55
Office buildings	Executive and private offices	35	45
	Conference rooms	35	45
	Teleconference rooms	30	35
	Open-plan offices	45	50
	Corridors and lobbies	45	55
Hospitals and clinics	Patient rooms	35	45
	Wards	40	50
	Operating rooms	40	50
	Corridors and lobbies	45	55
Courtrooms	Unamplified speech	35	45
	Amplified speech	40	50
Performing arts spaces	Drama theaters, concert and recital halls	25	30
	Music teaching studios	30	35
	Music practice studios	35	40
Laboratories	Testing/research with minimal speech communication	55	65
	Extensive phone use and speech communication	50	60
Churches, mosques, synagogues	General assembly with critical music programs	30	40
Schools	Classrooms	35	45
	Large lecture rooms with speech amplification	35	45
	Large lecture rooms without speech amplification	30	40
Libraries		35	45
Indoor stadiums, gymnasiums	Gymnasiums and natatoriums	50	60
	Large-seating-capacity spaces with speech amplification	55	65

Adapted from ASHRAE (20011d), Chapter 48; ASA (2008, 2010); and CEN (2007).

- Identification (manufacturer, model number, and serial number) of the acoustic instrumentation used and date of last calibration
- Names of the persons conducting the measurements
- Date and time of day of each measurement
- Microphone location for each measurement
- Notation of whether the measurement microphone was handheld or mounted on a tripod
- General description of the room including the room name or number and the approximate floor area
- General description of the surface treatments and the room occupancy
- General description of the HVAC system (including operating conditions and room temperature at the time of the measurements)
- General description of whether windows and doors are open and the origins of any intruding noise
- Average sound level (L_{eq} in dB(A)) for each measurement location
- Estimates of T_{60}, where applicable, and a copy of the calculation sheet

If Diagnostic Measurement corrective actions were taken, building operators should be made aware of how successful the corrective actions were in resolving the sources of acoustic dissatisfaction. The report should indicate the sound pressure levels before and after the actions were taken.

TOOLS AND AIDS

Appendix J includes sample Diagnostic Measurement level spreadsheet tools that are included on the companion CD, such as an example of sound level (L_{eq} in dB(A)) measurements in the occupied spaces with excessive background noise and an example of a reverberation time (T_{60}) calculation.

4 Advanced Analysis Procedures

ENERGY

INTRODUCTION

You may know from investigations at the Basic Evaluation and Diagnostic Measurement levels that a building is using more energy than it should. However, you may not know the reasons for this; Advanced Analysis is needed to dig deeper to determine those reasons. The procedures and examples in this section will clarify this approach.

The Diagnostic Measurement energy performance evaluation focuses on major energy systems and end uses (i.e., chilled water, heating water, etc.). In contrast, an Advanced Analysis energy performance evaluation focuses in more depth on specific systems and equipment at higher levels of granularity (i.e., hourly or 15 min interval data, etc.), which provides greater insight into building operation. The primary focus of the Advanced Analysis level is data collection, analysis, comparison, and presentation so as to eliminate or reduce non-value-added energy consumption. It is anticipated that many of the recommendations at this level will involve modifications to building automation system (BAS) programming and components. These recommendations will be attractive to building owners since they typically involve low costs and quick paybacks and can therefore be paid for using operating funds versus capital funds.

The overall approach is to collect detailed interval data on building systems and equipment operation and compare that data to self-reference benchmarks to determine energy performance. Previous levels of analysis established that the whole building or major systems are not using energy efficiently relative to external benchmarks (peer buildings). In contrast, the purpose of measurement and evaluation at the Advanced Analysis level is to determine the locations and causes of specific energy consumption problems by comparing systems and equipment operations to their targeted energy-efficient operations, in the specific application or operational contexts. An additional goal is to ensure that energy is not saved at the expense of maintaining comfort, safety, or other conditions required for proper and productive service to the building occupants.

Self-reference benchmarks depend on building type, equipment type, and intended operation. For example, an air-handling unit (AHU) for a typical office building has a different benchmark than an AHU in a 24/7 in-patient hospital. The controls for the office building AHU would be programmed such that the AHU is off at nights and on weekends. However, in a hospital environment, we may want

TO THE COMMISSIONING TEAM

Sidebar to go near beginning of Chapter 4.

This Advanced Analysis activity may be included in the investigation and implementation phases of existing building commissioning (EBCx). The commissioning (Cx) team typically monitors the selection of a professional specialist and the work of that consultant during all steps of the Advanced Analysis process, especially verification of corrective actions. After implementation, the Cx team would transition the activity to the building operators as part of the hand-off and ongoing Cx phases of EBCx.

to focus on the airflow amounts instead and ensure they do not substantially exceed code requirements.

A key assumption is that most buildings undertaking analyses will have BASs that allow for trending and collection of data on systems and equipment. The use of a BAS is generally the most cost-effective method for collecting large amounts of data. However, many situations call for the use of site-specific, component data loggers as well, for which there are many capable and increasingly sophisticated options.

There are software products available that make working with large amounts of data from the BAS or data loggers much easier. An example of such a tool is the *Universal Translator* (the UT), the use of which is free as it is funded by the California Energy Commission (PEC 2012). The UT is a powerful data analysis software program that includes automated tasks developed for detailed analysis of large amounts of real-world data from data loggers and/or BASs. It includes features such as standardizing time-series data to common intervals, working with missing data, generating charts and statistics, etc. The UT was used to generate all of the charts in the examples presented in Appendix E of this Guide. More information can be found at www.utonline.org.

PERFORMANCE MEASUREMENT PROCEDURE

The Advanced Analysis process for energy begins with development of a plan followed by a procedure to implement that plan. An overview of the process is presented in the Figure 4-1 flowchart.

Identify Scope of Analysis

The first step in the process is to identify the project scope. The consultant should first review previous data and findings from the Basic Evaluation and Diagnostic Measurement levels to identify the problems areas. For example, perhaps the lighting systems are acceptable but the HVAC systems are suspected to be the high energy users. The consultant should identify which systems are to be monitored in detail, such as chillers, boilers, AHUs, pumps, packaged rooftop units (PRTUs), etc. The consultant should then establish specific goals to be accomplished, such as reducing chiller plant energy use or reducing simultaneous heating and cooling at variable-air-volume (VAV) terminals.

It is recommended that the consultant keep an open, systems view regarding the investigation of the selected systems and should not unnecessarily limit the scope. For example, the consultant should not just analyze the AHUs but also ana-

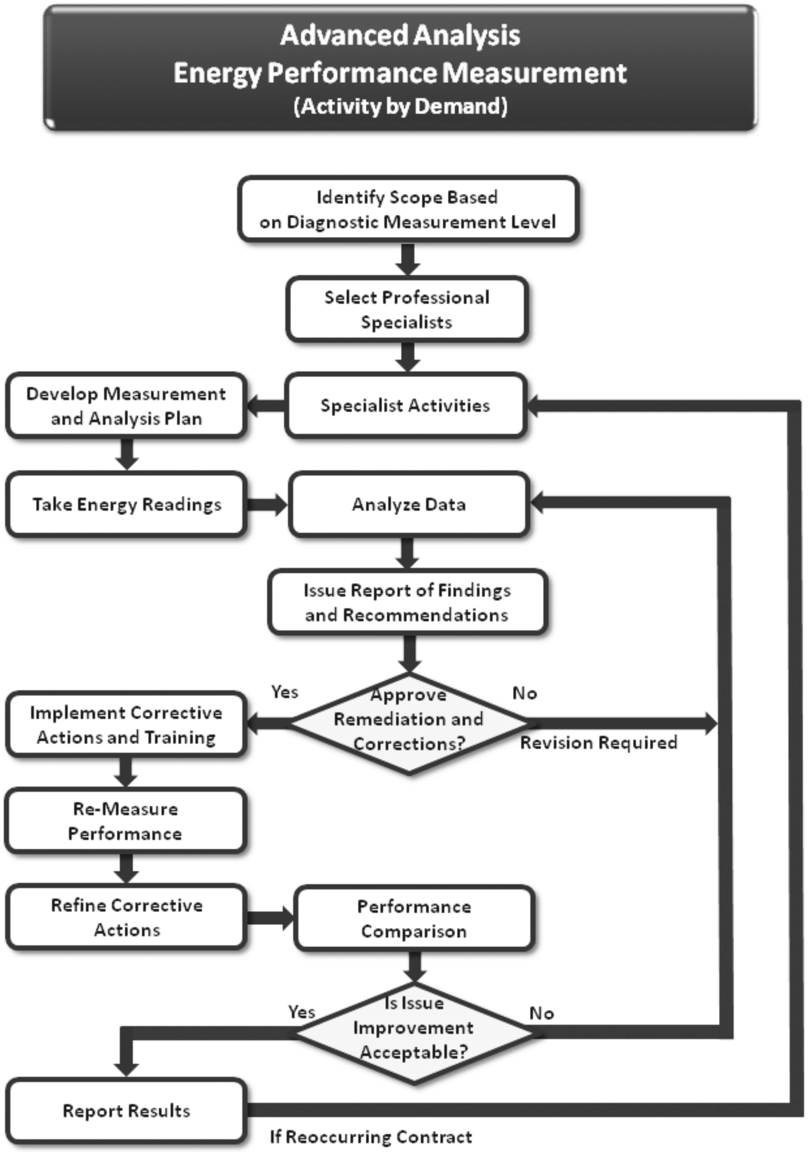


Figure 4-1 Energy Advanced Analysis Performance Measurement Procedures

lyze the VAV terminals. One should also evaluate how AHU operation impacts chiller plant operation, etc. Perhaps an AHU supply air setpoint has been set so low that the AHU cannot meet it but the chilled-water valve is open 100% all the time trying to meet that setpoint. The complex interactions among systems must be understood when developing the scope.

Select Professional Specialists

An Advanced Analysis energy investigation can be led and/or conducted by a single individual or an entity. The individual would likely be a consultant external to the organization, but he or she could be internal. The consultant often works with a team (typically the Cx team) to identify and correct problems. A diverse team with a wide range of expertise helps ensure that energy is not saved at the expense of maintaining comfort, safety, or other important facility operation parameters. A diverse team also helps to generate a wider range of ideas to improve energy performance. It is recommended that a licensed professional consultant manage the process.

Consultant Qualifications

The consultant could be an energy engineer, commissioning authority (CxA), etc. More importantly, the consultant should have experience not just with data analysis but also facility design and operation and should be capable of communicating with the clients in their particular business language. The consultant should also possess detailed knowledge of utility rate structures for analysis of potential energy cost savings. He/she should possess detailed knowledge of facility HVAC systems operation, automatic temperature controls, BASs, energy efficiency measures (EEMs) or energy cost reduction measures (ECRMs), and measurement and verification techniques, including spreadsheet analysis and working with database programs. Finally, the consultant should be capable of reading, modifying, and writing control programs using the facility's BAS or be very comfortable working with someone who can.

Assemble Supporting Team

The team supporting the consultant can include the following:

- *Facilities operation and maintenance (O&M) staff:* The O&M staff provides access to the building and to building information such as key drawings, equipment submittal data, BAS documentation, etc. In addition, safety specialists from the facility staff, such as lab directors and environmental compliance managers, can help ensure that proposed energy modifications are implemented safely.
- *BAS controls engineer and/or technician (a third-party vendor):* Controls engineers can help with reviewing and explaining existing programming, can help with setting up trends and downloading trend data, and can be very helpful with modifying key BAS programming functions.
- *IT staff:* The on-site IT professional can provide off-site Web access to BASs via a virtual private network (VPM) connection and can provide help with collecting data via database programs.
- *Other team members:* Other team members can include vendors of software designed to use the BAS for collecting, analyzing, and presenting large amounts of energy data. The team can also include equipment vendor representatives (i.e., for lighting, metering, HVAC, boilers, chillers, etc.), who can provide data on how equipment and systems are supposed to function. Other team members may include mechanical and electrical contractors who can assist with pricing proposed solutions.

Develop Measurement and Analysis Plan

This plan addresses detailed measurement and analysis of data and comparison to self-reference benchmarks through the following steps:

1. Determine what data will be collected and the duration of collection (i.e., two weeks, three months, one year, continuous, etc). In addition to building energy data, also collect ancillary systems operation data to help diagnose performance. This can include operating temperatures and set-

points, airflows, equipment status, valve and/or damper positions, variable-frequency drive (VFD) speeds, etc.

2. Establish metering and measurement approaches, including which instruments will be used. *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency* (FEMP 2011) is recommended as a resource. Metering points may be permanent as included in the energy management and control system (EMCS) or BAS, may be IP Web-based or included in the power management system, may be data loggers or manually read meters. Automated meters are recommended because they provide more data over multiple time intervals, which provides a better understanding of building systems operation. VFDs also are a great source of electrical consumption data (i.e., kilowatts and kilowatt-hours) for fans and pumps (no additional submetering required).
3. Determine how the data will be collected and what software will be used for analysis (i.e., a manual or an automated approach). For example, trend logs can be recorded in the EMCS/BAS, downloaded to a computer, and then imported into analysis software (for example, the UT [PEC 2012]), a spreadsheet, or both for analysis. Numerous programs are available that can automate the data collection, graphical display, analysis, diagnosis/fault detection, and reporting processes to varying degrees. Automated fault diagnostic tools can facilitate the detection of problems that compromise energy performance (Friedman and Piette 2001).
4. Finally, it is important to establish self-reference benchmarks for the building and/or each equipment or system to be monitored. Such benchmarks should be developed by experienced practitioners who understand how building energy systems are supposed to operate. They should be based on equipment type (i.e., lighting, chiller, boiler, AHU, pumps, VAV terminal, etc.), operating schedules, or project design information. For example, suppose a water-source heat pump loop has two circulation pumps controlled by a VFD to maintain the loop differential pressure setpoint, but only one pump should be running at any given time. If both pumps are running all the time at 90% speed, generating a differential pressure substantially above the setpoint, the pumps have failed their benchmark and corrective action is necessary.

Collect Performance Data

Use whatever data collection method was chosen in developing the measurement plan, of which multiple options are available. Connecting remotely to the site EMCS/BAS to download data files is common. However, if remote access cannot be arranged, the data can be downloaded and made available through a variety of electronic methods.

The least desirable option is to collect the data files manually at the site, modifying their format for import into the analysis program; this approach takes time and therefore costs money. The best option is to store the data in the proper format directly in an SQL-compliant database program. The data can then be remotely queried and automatically retrieved, or the program will directly generate graphics for review. Whether either of these extremes is used depends on factors such as the size of the facilities, the magnitudes of the energy use and costs, and the recurring nature of the work.

Analyze Data

Use the UT (PEC 2012) or a spreadsheet or both (or other applicable programs) for the analysis of the collected data. A graphical approach is recommended because it can succinctly characterize and communicate the essential behavior of systems while leaving out unimportant details. It takes an experienced analyst to develop a chart so that it captures the essence of what you want to show. In addition, the graphical approach displays what the system is doing much better than a verbal explanation or a written narrative.

The examples in the Tools and Aids subsection of this energy Advanced Analysis section illustrate the graphical methods for analyzing the data to identify problems with energy-consuming systems.

Conduct Performance Comparison

Compare current performance to past performance (self-reference) and to baseline databases (peer buildings if available). Use the graphical methods described previously.

Issue Report of Findings and Recommendations

The report should include a summary of existing systems, a description of the approach taken for analysis, the data collected, and charts and tables, including an explanation of the graphics and the key conclusions drawn from them. The report should also identify items that require correction, written in a succinct scope-of-work format, using language that can be understood by contractors doing the implementation and by facility operators. Design professionals should be engaged as necessary to develop the corrective action list.

Examples of corrective actions include making adjustments to existing operating schedules, developing operating schedules, adjusting operating setpoints, installing occupancy sensors and/or carbon dioxide (CO_2) sensors, changing ON/OFF controls to proportional controls, upgrading instruments to those with better accuracy, replacing failed sensors, installing VFDs, and adjusting EMCS programming.

The report should also include cost estimates for the recommended corrective actions, which can be developed by working with contractors (i.e., get real pricing information!), as well as anticipated energy cost savings.

Implement Corrective Action Plan and Training

It is recommended that Cx be conducted to verify that the corrective actions have been implemented properly. There will be issues that may require adjustments to the scope of work, or it may be discovered that a particular item costs more to implement that realized.

To implement effectively the corrective actions it is strongly recommended that training of facilities operating staff be conducted. This can be formal training but can also be as simple as briefing the facilities operation staff on what they are to accomplish. If the operations staff doesn't understand how the system is supposed to operate for energy efficiency, they will likely override the adjustments. Finally, get the operations staff involved in implementing as many of the corrective items as possible. If they are involved in the process and invested in the outcome, this greatly increases the chance of success.

Remeasure Performance and Compare

After corrections and adjustments have been implemented, remeasure and then compare new performance to past performance to verify the improvement level achieved. Use graphics similar to those in the original report so that it is easy to compare and contrast pre-retrofit and pre-retrofit performance. Use of the same analysis approach and metrics will clarify whether the corrective actions worked to save energy.

Are issues resolved? If not, repeat the steps and refine the corrective actions until the issues are resolved.

Report Results

Issue a final report update, documenting that the corrective actions were successfully implemented. To document performance improvement use graphics and metrics similar to those previously used to document performance deficiencies.

TOOLS AND AIDS

The best way to communicate the key analysis concepts described in this section is through examples. Appendix E presents two practical examples that illustrate how to do an advanced analysis of energy systems; these two examples as well as five additional examples are included on the CD accompanying this Guide.

These case study examples, listed in Table 4-1, are primarily based on the analysis of interval data. All were generated using the UT (PEC 2012).

The examples vary in complexity, but all are intended for building owners, facilities managers, practicing engineers, CxAs, energy auditors, and/or existing building commissioners; they are presented to show that the approaches are feasible for most people to implement. None of these examples illustrate capital-intensive equipment replacements. Instead, they illustrate that the most cost-effective approach is to modify and improve the operation of existing equipment. This allows improvements to be paid for out of operating funds rather than capital funds.

A final item to note is that the EMCS/BAS present in many buildings can be adjusted to provide significant energy savings at low cost. Often this involves just modifying a few lines of programming code, re-enabling automatic control, replacing a failed sensor, or adding low-cost sensors.

Table 4-1 Case Study Examples of Advanced Analysis of Energy Systems

Example	Building Type	Application
1	Small commercial office building #1	Review of small split direct-expansion system operation
2	Large university research laboratory building	Review of measured steam loads versus building energy model predictions
3	Large state government office building #1	Review of AHU and lighting systems operation
4	Large state government office building #2	Review of water-source heat pump loop pump operation
5	Large state government office building #2	Review of operation of dedicated outdoor air system with energy recovery
6	Small higher education teaching facility	Review of pre-retrofit and post-retrofit VAV terminal operation and building energy performance for an energy retrofit project
7	Small commercial office building #2	Review of 75 ton PRTU economizer operation

WATER

INTRODUCTION

An Advanced Analysis water analysis involves taking more detailed water-use readings and involves advanced usage analysis, normally employing a specialist or consultant to provide the in-depth analysis and associated expertise that provides advanced water-usage reduction strategies.

Advanced Analysis water measurement protocols use the utility water meter and submeters to verify performance of key water-using systems in the facility. These measurements are used in detailed analysis of past water-use patterns and to predict future performance. Submeters and advanced normalization techniques are used to improve the granularity of the readings so water use can be observed for specific end uses. This allows improved analysis of adjustments and changes to each of the measured flows, allowing operators to fine-tune the water use.

PERFORMANCE MEASUREMENT PROCEDURE

The Figure 4-2 flowchart outlines the procedures for lowering water use using Advanced Analysis performance measurement protocols. These protocols use the same process as at the Diagnostic Measurement level but add more submeters and additional normalization for increased granularity and to increase the accuracy of the readings. Advanced Analysis procedures also increase the level of analysis and recommended improvements over the Diagnostic Measurement level.

Develop Measurement and Analysis Plan

The Advanced Analysis performance plan builds on the Basic Evaluation and Diagnostic Measurement performance plans by adding the following criteria:

- A specific target for the level of water reduction required and what improvements are desired.
- Identification of the specialist needed to accomplish the plan. (Is outside assistance needed?)
- A list of required submetering or a list of the results of any specialist activities. Possible submetered flows and interval units are as follows:
    - Cooling tower makeup water, gal/interval (L/interval) or gal/ton-hour (L/kWh)
    - Steam boiler makeup water, gal/interval (L/interval) or gal/therm (L/kWh)
    - Kitchens, gal/interval (L/interval) or gal/plate served (L/plate served)
    - Subdivided landscape areas, gal/interval (L/interval) or gal/unit area (L/unit area)
    - Pools, fountains, and water features, gal/interval (L/interval)
    - Process water use, gal/interval (L/interval) or gal/unit produced (L/unit produced)
    - Cleaning water use, gal/interval (L/interval)
    - Recycled water use, gal/interval (L/interval)
    - Rain water harvesting use, gal/interval (L/interval)
- A list of advanced normalization that is desired or a statement of what is expected of normalization recommendations from any specialist.

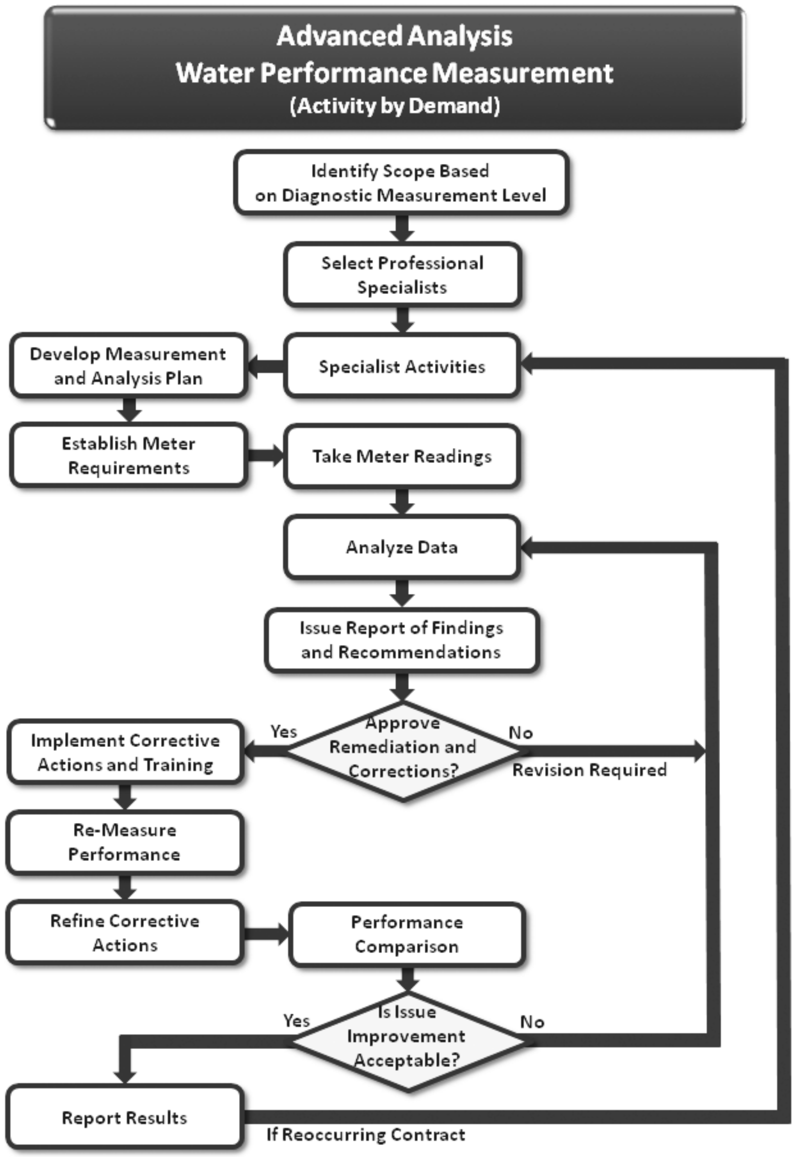


Figure 4-2 Water Advanced Analysis Performance Measurement Procedures

Include a description of the standard measurement format and normalization time interval to be used. While measurements at the Diagnostic Measurement level use monthly data, Advanced Analysis measurements may use shorter periods, such as daily or hourly, or may use monthly data intervals.

Collect Building Space Characteristics

In addition to the basic information about the facility collected under the Basic Evaluation and Diagnostic Measurement levels, data about other submeter normalization variables need to be added:

- Design data for the average number of occupants by gender per day for each month.

- Design water flow rates of other submetered flows and what measurement interval will be used. The interval may be monthly, daily, hourly, or more frequently depending on the capability of the meter and the data collection system or depending on the importance of the flow use over time.

Conduct Performance Measurement

For the Advanced Analysis level the measurements are taken from utility or local monthly water meter readings and submeter readings. This data can be obtained from monthly utility water bills or taken directly from the water meter manually. If taking manual readings verify the units used at the meter. Many utilities use 748 gallons per meter as the unit of measure, so verify this amount from your utility or meter manufacturer.

Advanced systems normally use automatic data collection that feed data into a BAS or they may use IP network-based meters that feed data to a Web page for aggregation and analysis. The advantages of these meters are the lower cost of labor for meter reading and that the data is usually more accurate. Domestic water submeters should always be of the positive displacement type that will read down to zero flow with a digital pulse output that can be aggregated by the data collection system. Analog flowmeters that are used for process flows do not work well as water-use meters since their accuracy near zero flow is very poor.

In addition to the meter readings, the normalization variable data need to be collected and recorded. Standard normalization variables could include the following:

- Cooling tower makeup water normalization data (total HVAC load over the interval time)
- Steam boiler makeup water normalization data (total boiler load over the interval time)
- Kitchens water normalization data (plates served or people served over the interval time)
- Subdivided landscape areas normalization data (inches of rain and temperature of the landscape area over the interval time)
- Pools, fountains, and water features normalization data (evaporation rate over the interval time)
- Process water use normalization data (units produced over the interval time)
- Cleaning water use normalization data (cleaning events during the interval time)
- Recycled water use normalization data (full-time equivalent [FTE] occupants over the interval time)
- Rainwater harvesting use normalization (inches of rain over the interval time)

Data Analysis and Water-Use Calculations

Leak Calculations

Leaks from plumbing fixtures can be estimated. If a leak is observable, count the drops over a 10 s period and determine the approximate leak rate from Figure F-1 in Appendix F.

Plumbing Fixture Water-Use Calculations

Determine the FTE occupants by gender and calculate the number of daily average visitors. An FTE occupant is defined as one person for an eight-hour period, distinguished by gender. To account for visitors, divide the average number of visitors times the daily average hours per stay and divide by eight hours to determine the equivalent daily average number of transient occupants and add that number to the normal building occupants. From Table G.2 calculate the fixture water flow using the following formulas:

(occupants by gender) × (fixture flow per use) × (number of uses per day) = gpd (L/day)

(occupants by gender) × (fixture flow) × (number of uses per day) × (average time per use) = gpd (L/day)

(number of fixtures) × (number of cleaning activities per day) × (gallons per cleaning activity) = gpd (L/day)

Cooling Tower Water-Use Calculations

From the total HVAC load, determine the average condenser water flow rate in gallons per minute (m^3/h) and the average differential temperature between the inlet and outlet water. From design or use records, determine the average cycles of concentration. To determine water use, use the following formulas from the free, noncommercial Eng-Tips Forums Web site, www.eng-tips.com (Tecumseh 2012). Permission will be required to re-print this information.

A water balance around the entire system is:

$$M = E + D + W$$

Since the evaporated water (E) has no salts, a chloride balance around the system is:

$$M(X_M) = D(X_C) + W(X_C) = X_C(D + W)$$

$$X_C/X_M = \text{cycles} = M/(D + W) = M/(M - E) = 1 + \{E/(D + W)\}$$

From a simplified heat balance around the cooling tower:

$$(E) = (C)(\Delta T)(c_p)/H_V$$

where

M	=	makeup water, gpm (m^3/h)
C	=	circulating water, gpm (m^3/h)
D	=	draw-off water, gpm (m^3/h)
E	=	evaporated water, gpm (m^3/h)
W	=	windage loss of water, gpm (m^3/h)
X	=	concentration of any completely soluble salts (usually chlorides), ppmw
X_M	=	concentration of chlorides in makeup water (M), ppmw
X_C	=	concentration of chlorides in circulating water (C), ppmw
cycles	=	cycles of concentration = X_C/X_M

H_V = latent heat of vaporization of water, ca. 1000 Btu/lb (2260 kJ/kg)
ΔT = water temperature difference from tower top to tower bottom, °F (°C)
c_p = specific heat of water, 1 Btu/lb/°F (4.184 kJ/kg/°C)

Windage losses (*W*), in the absence of manufacturers' data, may be assumed to be:

W = 0.3% to 1.0% of circulating water (*C*) for a natural-draft cooling tower
W = 0.1% to 0.3% of circulating water (*C*) for an induced-draft cooling tower
W = about 0.01% of circulating water (*C*) if the cooling tower has windage drift eliminators
W = about 0.01% or less of circulating water (*C*) if the cooling tower has windage drift eliminators

Note: *Draw-off* and *blowdown* are synonymous. *Windage* and *drift* are also synonymous.

Concentration cycles in HVAC cooling towers usually range from 2.5 to 3.5 but may be higher depending on the chemical treatment or filtering programs. Savings from higher cycles of concentration declines as cycles are increased.

Landscape Water-Use Calculations

Obtain the evapotranspiration rate (*ETo*) from local meteorological sources and determine vegetation type and the species factor, density factor, and microclimate factor.

The species factor is separated into low, medium, and high water use; the plant species density factor represents the shading of the planting area. A low-density factor is where trees and plantings shade 60% of the ground, an average-density factor is where trees and plantings shade 90%–100% of the ground, and a high-density factor is where a tree canopy shades plantings that shade the ground.

The microclimate factor adjusts for areas that allow sun or wind to increase the evaporation rate of the soil. High microclimate factors are parking lots, west sides of buildings, west and south sides of slopes, meridians, and areas exposed to wind tunnel effects. Low microclimate factors include shaded areas, areas protected from the wind, north sides of buildings, courtyards, areas shaded by building overhangs, and north sides of slopes.

Determine the reference *ET* rate (ET_L) as follows, using the landscape factors from Table 4-2:

$$ET_L = ET_O \times K_L$$

$$K_L = K_S \times K_D \times K_{MC}$$

where

K_L = landscape factor
K_S = species factor
K_D = density factor
K_{MC} = microclimate factor

Calculate the baseline case using the irrigation type factors from Table 4-3:

$$TWA = \text{area} \times (ET_L/IE) \times CE \times 0.6233 \text{ gal/ft}^2\cdot\text{in.}$$

Table 4-2 Landscape Factors

Vegetation Type	Species Factor (K_S)			Density Factor (K_D)			Microclimate Factor (K_{MS})		
	Low	Average	High	Low	Average	High	Low	Average	High
Trees	0.2	0.5	0.9	0.5	1.0	1.3	0.5	1.0	1.4
Shrubs	0.2	0.5	0.7	0.5	1.0	1.1	0.5	1.0	1.3
Groundcovers	0.2	0.5	0.7	0.5	1.0	1.1	0.5	1.0	1.2
Mixed trees, shrubs, groundcovers	0.2	0.5	0.9	0.6	1.1	1.3	0.5	1.0	1.4
Turfgrass	0.6	0.7	0.8	0.6	1.0	1.0	0.8	1.0	1.2

Data source: USGBC (2005).

Table 4-3 Irrigation Type

Type	IE	CE Dry Climate	CE Wet Climate
Sprinkler	0.625	0.25	0.5
Drip irrigation	0.900	0.25	0.5

Data source: USGBC (2005).

$$TPWA = TWA - \text{reuse water}$$

where area is in square feet (square meters), reuse water is in gallons (litres), and

TWA = total water applied, gal (L)
ET_L = evaporatio rate, in. (mm)
IE = irrigation type
CE = controller efficiency
$TPWA$ = total potable water applied, gal (L)

Calculate the design case.
Calculate the percent savings.

Performance Comparison (Benchmarking)

To Past Performance

Normalized current performance is compared to normalized past performance using a modeling program or an expanded worksheet that compares the current months' normalized data to the respective period's data for the past time periods.

To Baseline Databases

Once past usage is established, use ENERGY STAR or other national databases to rate the existing facility water use to that of similar facilities. Record this rating for future reference.

To Design Baseline Data

It is possible to compare the building water use to the original design water use by calculating the plumbing fixture estimated flow and adding the predicted landscape water use and the predicted water flows from other major uses.

Identify Issues Needing Action and Take Corrective Actions

At the Diagnostic Measurement level, corrective actions used the improvement suggestions from Appendix A or other water-reduction information sources to determine steps that can be taken to reduce water use. At the Advanced Analysis level, the specialist should produce technical recommendations, including a complete analysis of water use and projected water savings and associated costs. The design information in Appendix F may also be used to identify water-saving strategies or to calculate the water use in existing systems.

A typical suggestion is to lower the water pressure to the minimum required to operate the plumbing fixtures on the highest level of the building. Other suggestions include the following:

- Repair all leaks using the leak calculation rates in Figure F-1 in Appendix F. This number can be used to anticipate the future water reductions.
- To determine the water use and cost savings from possible fixture replacements with more efficient fixtures, use the calculations and use tables in Appendix F.
- Lower landscape water times and flows to the minimum required for the existing plantings. This can be determined by using the calculation included in Appendix F to approximate the minimum required water by plant type. Basic soil moisture measurements may also be required to determine the minimum water requirement.
- Increase cycles of concentration of cooling towers or reduce the total tower load.
- Increase the amount of condensate return to a steam boiler.
- Check whether cooling water consumption can be reduced with automatic valves.
- Check whether process changes can lower the water used in the operation of that process.

Because water use is normally regarded by most occupants and operators as not important, the most important adjustment to lower water use is to keep focused on all uses and to keep the occupants focused on water-use reduction.

Remeasure Performance

Once corrections and adjustments have been made, remeasure the water usage based on the next utility bill or by taking manual meter readings.

Compare New Performance to Past Performance

Using the new period's measurements, compare this time period to the same time period in the past year to determine if the adjustments or corrections have made a difference. The collected data must be normalized for each normalization variable per measured water use.

Report Results

As described for the Basic Evaluation level, reporting the results to managers responsible for the financial aspects of the facility, operators, and occupants is very important to the success of any water reduction program. It is recommended that the specialist produce graphs of the water uses comparing current use to past use and to baseline data.

TOOLS AND AIDS

The Advanced Analysis level anticipates that the specialist who conducts water use and recommends corrections will provide all the tools required. The specialist may use the Diagnostic Measurement tools and aids, modified to fit the facility's exact requirements.

IEQ THERMAL COMFORT

INTRODUCTION

There is not a widely established thermal comfort consultancy as there is for lighting/daylighting, acoustics, and IAQ. Comfort typically has been handled by HVAC technicians setting the thermostats according to simple comfort rules (sometimes a fixed value year round) or in response to occupant complaints. Occasionally comfort performance is addressed by design engineers, usually in the context of fixing a problem. Their design tools, typically design-day analyses for sizing or annual hourly simulations for energy prediction, tend to focus on temperature, relative humidity, and air supply volume, overlooking other thermal elements that strongly affect comfort. Air speeds in the occupied space and the radiant fields coming from windows or other heated and cooled surfaces are not often considered.

PERFORMANCE MEASUREMENT PROCEDURE

The basic ASHRAE Standard 55 (2010b) comfort requirements are summarized in the analysis section of the Diagnostic Measurement chapter. However, satisfying those requirements does not necessarily result in a system that is energy efficient or even optimally comfortable. To optimize thermal comfort performance one must take advantage of all the thermal elements available in the indoor environment as well as the behavioral responses of the occupants to their thermal environment. Such elements have recently been incorporated into Standard 55 based on recent comfort research. These are described in the subsections that follow.

In this context, Advanced Analysis is a process used to eliminate errors and unnecessary traditional practices that limit optimal performance and to implement the best feasible design and operation solutions. In some cases, this may mean employing new technologies that overcome the limitations imposed by existing systems. The main strategies can be categorized as follows:

- Adjust thermostat and supply air temperature setpoints for climate-adaptive seasonal comfort, including air movement cooling and radiant heating.
- Provide local thermal comfort control options.
- Reduce excessive minimum supply air volumes.
- Control direct sunlight in work areas.
- Control humidity independently of supply air temperature.

These strategies, each of which has the ability to both improve comfort and reduce HVAC energy, are described in the following subsections; the process is outlined in the Figure 4-3 flowchart.

Adjust Thermostat Setpoints for Energy-Efficient Thermal Comfort

Because of interpersonal differences in physiology and dress habits, it is not possible to have everyone comfortable at any single temperature. The practical

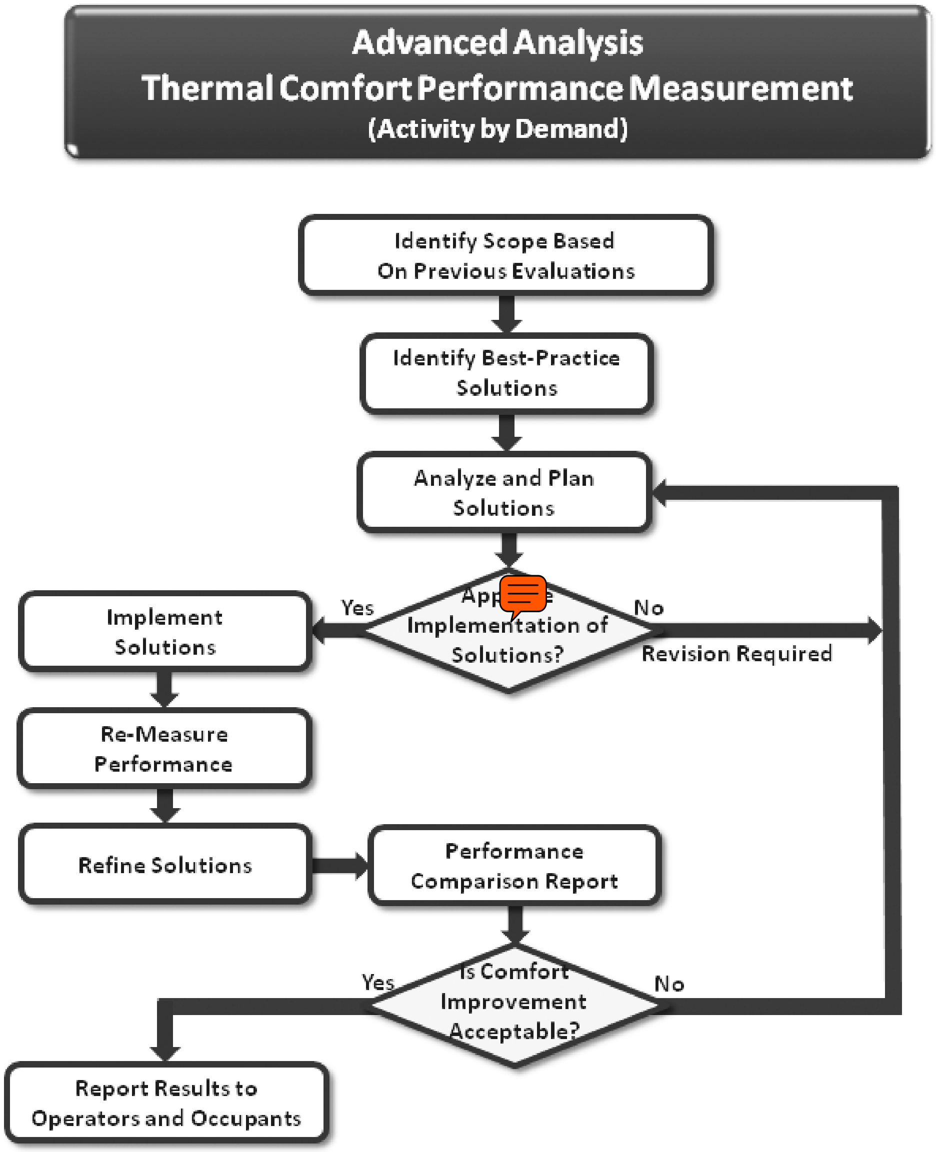


Figure 4-3 Thermal Comfort Advanced Analysis Performance Measurement Procedures

maximum of people regarding the space temperature as acceptable in offices appears to be 80%, which applies equally across a range of temperatures (Zhang et al. 2011). Within that temperature range some people become too warm and an equal number become too cool. This realization is based on field observations, not theory or comfort modeling.

However, it is very common to find a thermostat dead-band range of 72°F–74°F, or even narrower, in use year-around. This range is in the lower half of the winter comfort zone. In the United States, the average indoor temperature setting is now cooler in summer than in winter. This practice not only wastes energy but also causes elevated discomfort and health symptoms in both seasons (Mendel and Mirer 2009). The reasons for this wasteful practice are several. One is that the minimum flow rates for VAV diffusers are set too high, causing zones with low internal loads to be overcooled. Another is that supply air temperatures are not reset when loads change, either daily or seasonally. Another reason results from dehumidification taking place in the same coil as supply air temperature, without reheat. The cold temperatures required for dehumidification cause overcooling in many zones.

For each degree Fahrenheit that the dead band can be extended, roughly 5% of heating or cooling HVAC energy use is saved, depending on the climate. Figure 4-4 shows energy savings in commercial buildings simulated for a range of climates (Hoyt et al. 2009a). There are few other measures that can generate this amount of energy savings in either new or existing buildings.

The first step in combining energy efficiency and high comfort performance is extending the dead band of ambient indoor temperatures (as controlled by the thermostat) to the allowable range specified in ASHRAE Standard 55 (2010b). In the following figures, temperature is indicated as *operative temperature*, an average of air temperature and the temperature of the surrounding room surfaces. For setting controls in typical buildings, however, the operative temperature can be assumed to be equivalent to the thermostat temperature.

In buildings with air conditioning, the dead band should be set according to Figure 4-5 (Figure 5.2.1.1 from Standard 55). It should be roughly 7°F (3.5°C) wide for a given clothing level. This band should move with the seasons to encourage appropriate climate-adaptive clothing behavior. Clothing insulation values for summer ensembles for men are 0.6 or 0.5 clo, representing slacks with long-sleeved or short-sleeved shirts, respectively. Reasonable winter values are 1.0 to 0.8 clo, representing a man's business suit with or without a vest. Women's clothing should be estimated as 0.1 clo less than men's clothing.

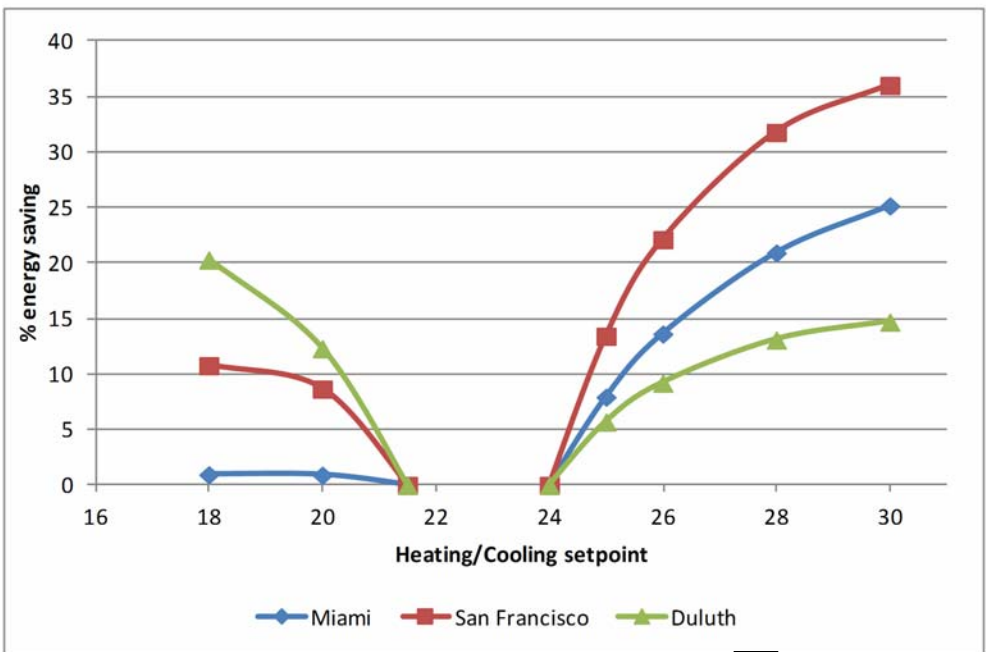


Figure 4-4 Heating and Cooling Energy Savings by Setpoint Range
Courtesy of Center for the Built Environment

At higher temperatures, occupants may perceive stuffiness. This is countered by a small amount of air movement at face level, such as 60 to 80 fpm (0.3 to 0.4 m/s). Such indoor air movement was traditionally available from operable windows, but it can also be supplied by area fans such as ceiling fans. Look for opportunities to introduce air movement in the occupied space, because such air movement can be generated more efficiently than cooling the entire space.

If the building has operable windows, the thermostat dead band can be based on the Adaptive Model (Figure 4-6). This model, which is based on empirical observations in occupied buildings, allows a slightly wider thermostat dead band (8°F–9°F [4°C–4.5°C]) that shifts with the seasons. Because it represents actual occupancies, it is not necessary to estimate clothing levels using the Adaptive Model.

Beyond using the full temperature comfort zones for air-conditioned and naturally conditioned spaces as shown in Figures 4-5 and 4-6, it is possible to further expand the thermostat setpoint dead bands. One may use area-wide air movement to raise the cooling setpoint temperature above the upper comfort zone boundary and area-wide radiant heating to lower the heating setpoint temperature below the lower boundary. These are described in the following sections. The need for air movement cooling is supported by extensive field observation (Hoyt et al. 2009b).

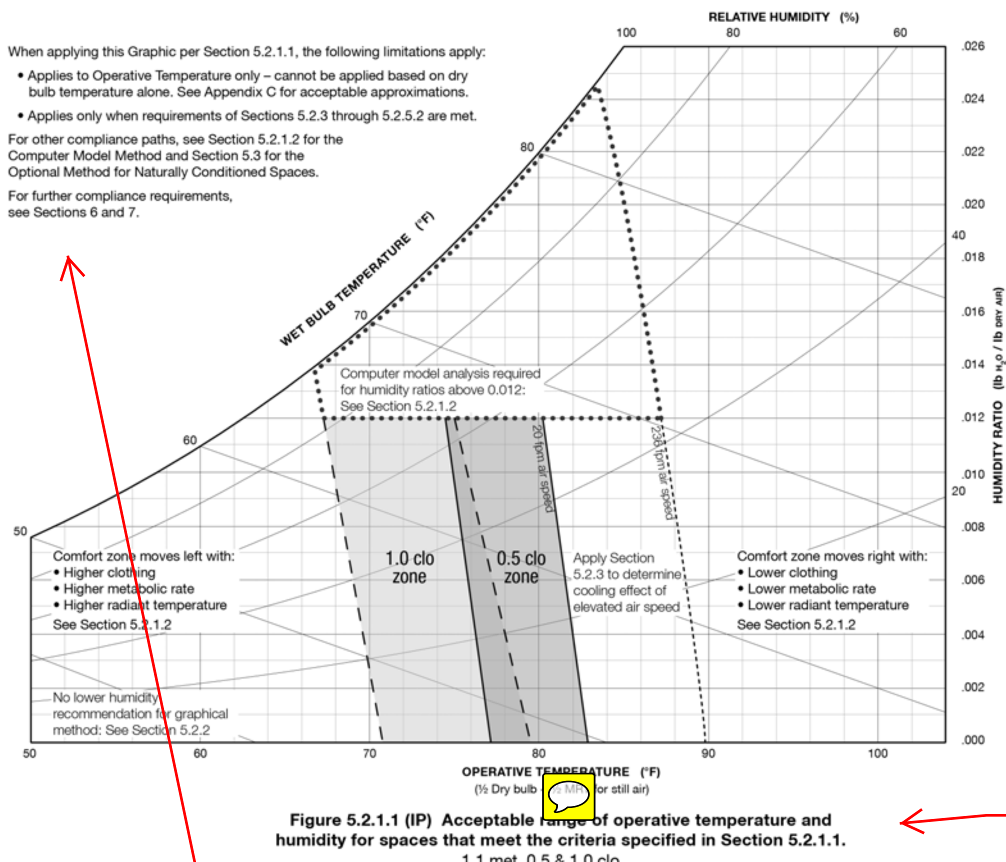


Figure 4-5 Acceptable Range of Operative Temperature and Humidity
Source: ASHRAE (2010b), Figure 5.2.1.1

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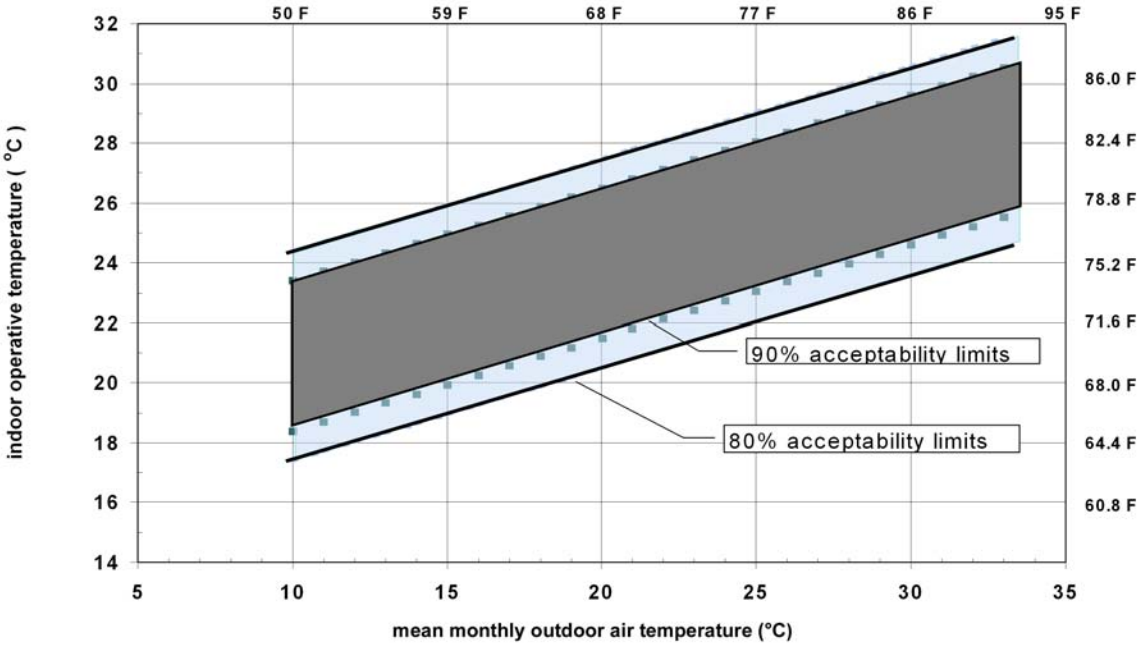


Figure 4-6 Acceptable Temperature for Naturally Conditioned Spaces
Source: ASHRAE (2010b), deDear and Brager (2002), Olesen and Brager (2004)

Air Movement Cooling (HVAC Buildings)

The light-grey zone in Figure 4-7 (Figure 5.2.3.2 from Standard 55, also Arens et al. (2010)] shows that the space temperature can be raised another 5°F (3°C) by adding up to 160 fpm (0.8 m/s) air movement in the occupied zone. The thermal comfort remains equal in this warmer zone. The air movement in the light-grey zone is a feature of the ambient environment that does not have to be under local control; it can be automatically controlled based on a temperature sensor. The "local control of air speed" area of the figure is addressed in the Provide Local (Personal) Options for Controlling Thermal Comfort section that follows.

Air Movement Cooling (Naturally Conditioned Buildings)

For buildings with operable windows, Standard 55 allows the Adaptive Model comfort zone boundary to be raised by air movement above 60 fpm (0.3 m/s), as reproduced in Table 4.3. This allows fans to be employed in naturally conditioned buildings to reduce the occurrence of discomfort during times when indoor temperatures exceed the Adaptive Model comfort zone.

Radiant Heating (All Buildings)

At lower temperatures, area-wide radiant heating in the floor allows the heating temperature setpoint to be lowered by 4°F (2°C). The "Adaptive" zone in Figure 4-8 shows the great extension to the conventional thermostat range that is possible by adding area-wide radiant heating and air movement cooling to a space conditioned to the full range of the Standard 55 comfort zones.

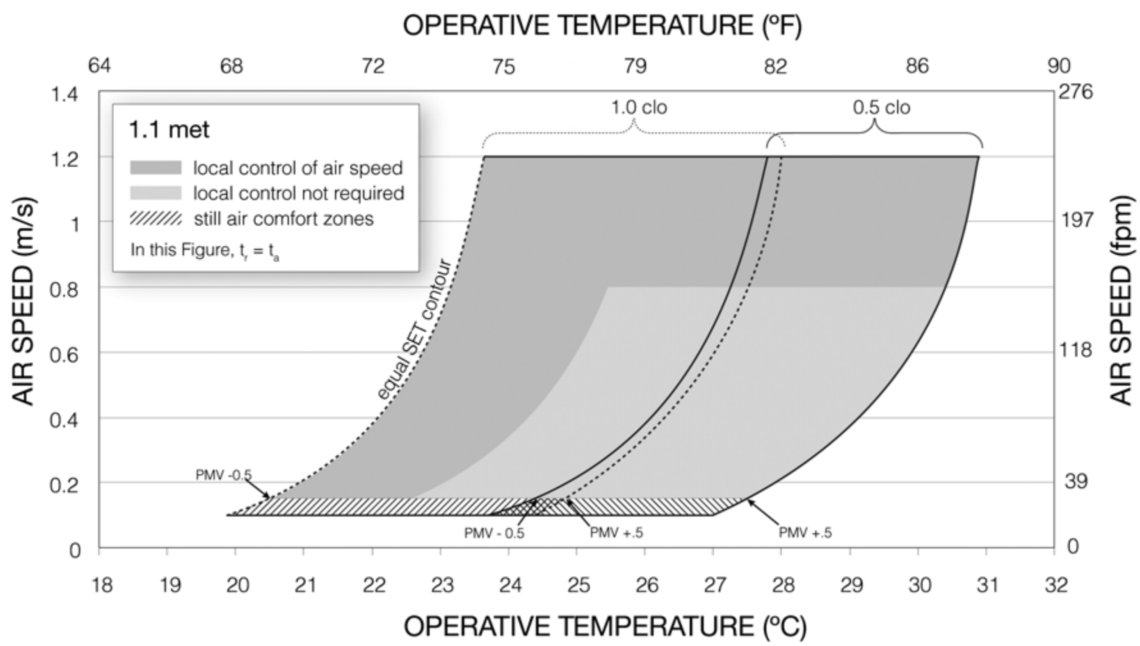


Figure 4-7 Comfortable Temperature Increases with Air Speed
Source: ASHRAE (2010b), Figure 5.2.3.2

Table 4-4 Increases in Acceptable Temperature Limits in the Adaptive Comfort Model (Figure 4-6) Resulting from Increasing Mean Air Speed above 60 fpm (0.3 m/s)

Mean Air Speed = fpm (0.6 m/s)	Mean Air Speed = fpm (0.9 m/s)	Mean Air Speed = fpm (1.2 m/s)
2.2°F (1.2°C)	3.2°F (1.8°C)	4.0°F (2.2°C)

Provide Local (Personal) Options for Controlling Thermal Comfort

Beyond this extended zone, comfort can be augmented through the use of systems that are under local or personal control and that warm or cool the occupants directly. The local application of warming or cooling to the human body is inherently much more energy-efficient than conditioning the temperature of the entire building, and it can provide equal comfort over a wider range of temperatures than is possible with ceiling fans or radiant-floor heating.

The "personal environmental control systems" zone in Figure 4-8 shows how far such systems can extend the ambient thermostat dead band while providing equal thermal comfort (Zhang et al. 2011). Personal environmental control (PEC) also makes it possible for all occupants in a space to be satisfied by allowing them to individually adjust for their interpersonal differences in comfort requirements. Uniform heating and cooling systems rarely produce thermally acceptable votes for more than 80% of the occupancy, whereas a PEC system tested in offices has been found to deliver 100% acceptable votes (Bauman et al. 1998).

PEC systems need to have sufficient corrective power to produce comfort for all occupants within the ambient temperature dead band. For a wide variety of applications, PEC systems provide about 9°F (5 K) cooling and 8°F (4 K) heating above and below the ambient comfort zone temperature. At the same time, PEC

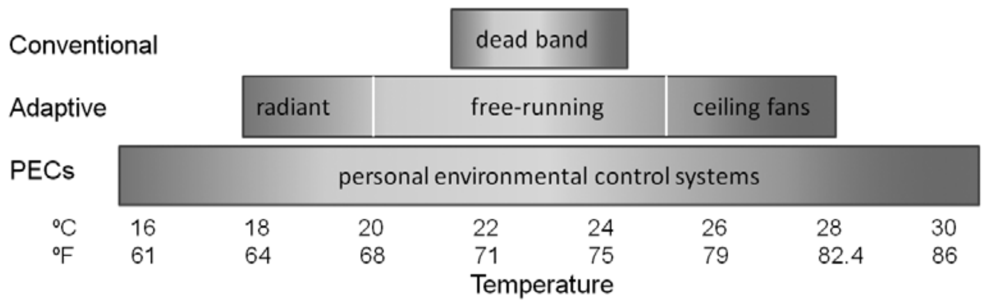


Figure 4-8 Extended Thermostat Dead Band Zones Providing Equal Comfort
Courtesy of Center for the Built Environment

systems must be energy efficient. It is possible to have local systems (such as conventional 500–1500 W heaters) that when widely used are not much more efficient than central heating; these should not be used for PEC.

Personal Cooling

For cooling, air movement must be perceptible within the occupied space, especially around the face region. It can be provided by operable windows and fans; ventilated and cooled seats are also possible.

- ***Windows:*** Although operable windows are discussed under the previous subheading Cooling Naturally Ventilated Buildings, the ASHRAE Standard 55 (2010b) Adaptive Model applies only in naturally conditioned spaces. Windows may also be used as personal control systems in mixed-mode buildings that are also mechanically air conditioned. Windows are effective at producing personally controlled air movement within nearby workstations. External wind pressure and buoyancy effects produce fluctuating breezes and temperature changes near the window that are readily perceived by the occupants as cooling them. However, occupants in workstations farther from the window are less likely to perceive air movement unless there are openings on opposing sides of the room, providing cross or corner ventilation (Brager et al. 2004; Carrilho da Graca and Linden 2002).

  In the warm season, opening windows may be detrimental if the external temperature or humidity is above that indoors. Some control systems employ signals (analogous to traffic lights) to suggest when occupants may best open or close windows. In thermal comfort Basic Evaluation and Diagnostic Measurement, the degree of compliance with such signals is observed so that problems can be corrected.

- ***Fans:*** Fans can cover areas with multiple occupants (ceiling or area fans). Group control of air movement by fans is provided for in the light-grey zone of Figure 4-7, as previously described. Fans can also be at the personal level as PEC devices, also known as *task-ambient conditioning* (TAC). Fans for cooling are most effective when they supply air movement to the occupant's facial region and hands and closely around the torso, as in ventilated chairs. The wattage of PEC fans can range from below 1 to 25 W, depending on the area covered and the fan's distance

Figure 4-9 Personal Environmental Control Devices (Fans and a Radiant Foot Warmer) in an Office
Photograph by Ed Arens; courtesy of Center for the Built Environment

from the occupant. Figure 4-9 shows nozzle fans on two workstation desktops.

Personal Heating

PEC radiant devices are most energy efficient when they focus radiation to the feet and hands. The radiation on the feet should preferably be on the top of the feet, and the radiation source should be in a reflective enclosure that minimizes the heat lost to the environment (see the foot warmer in Figure 4-9). PEC may also employ contact heating through conductive surfaces. For hands, the desktop or keyboard surfaces can be locally warmed with low wattage. Heated chairs are effective at conditioning the whole body; long used in cars, they are becoming available in office chairs.

Reduce Excessive Minimum Supply Air Volumes

In practice, minimum flow rates for VAV diffusers are often set too high, resulting in zones with low internal loads being overcooled. Overcooling is becoming a major comfort and health issue in the U.S., as mentioned previously (see also Mendel and Mirer [2009]; Choi et al. [2010]). The fan power consumed is also substantial (Hoyt et al. 2009a), constituting as much as 25% of HVAC energy use (Figure 4-10).

The high minimum flow rates (often 30% to 50% of the maximum flow) originate from a concern by manufacturers that low flows might cause insufficient mixing in the space and that cold supply air might dump on the occupants. The stability concern is not borne out in tests of VAV boxes and controllers at minimum flow rates of [illegible]% maximum (Dickerhoff and Stein 2007). The air exchange at 10% maximum exceeds the minimum requirements for ventilation. Buildings

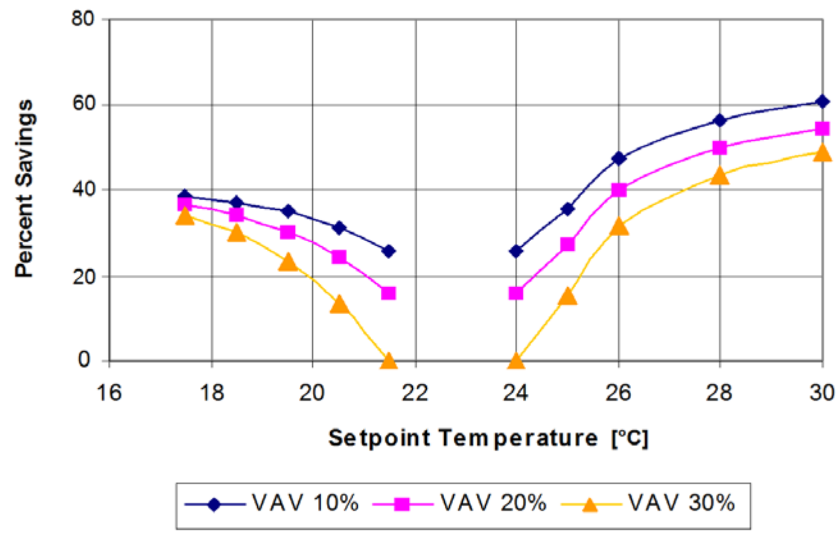


Figure 4-10 Annual Energy Use for an Office Building in San Francisco with Different Dead Bands and VAV Minimum fractions at 10%, 20%, and 30%

Courtesy of Center for the Built Environment

operating at low minima are not uncommon, and they are evidently more comfortable due to the decreased overcooling in zones with low internal loads. Reprogramming the zone VAV minimum flow to these values is a best-practice recommendation. If there is any doubt, a follow-on survey, such as the survey used during Basic Evaluation, can be used to detect whether such changes have caused any problems.

Provide Solar Control

It is unfortunately very common to find glazing that is installed for daylighting or view but that does not control direct beam sunlight. The unacceptable thermal conditions produced by unshaded and oversized windows cannot be efficiently corrected through HVAC cooling because the temperature differences required to offset direct solar gain on the human body are very large. The highly directional beam radiation also reflects off work surfaces and computer screens, impeding vision and legibility. Direct solar gain must be controlled directly before it hits the occupant, preferably before it enters the space. Solar controls (blinds, shades, changes to glass transmittance) help solve both thermal discomfort and visual glare.

ASHRAE Standard 55 (2010b) provides radiant asymmetry limits (horizontal and vertical), but these are intended for limiting longwave radiation exchange to and from building surfaces. The impact of direct sun on building occupants is not yet adequately addressed in this standard. A National Fenestration Rating Council report (Huizenga et al. 2006) recommends that for workstations there should be no

1. Note that although the air diffusion performance index (ADPI) in ASHRAE Standard 113 (2009d) employs air movement limits for rating the mixing effectiveness of overhead diffusers in laboratory tests, these limits apply only to a subset of comfortable occupied spaces and should not be used as comfort requirements in actual occupied spaces.

direct solar gain allowed on the occupant, even when it is filtered through screens; as little as 5% of incident radiation produces discomfort.

Preferable solutions involve the following:

- External shading (fixed or moveable). Preferably the shading also can act as a light shelf to redirect sunlight to the ceiling, where it becomes a useful light source.
- Internal venetian blinds. Blinds allow views out while blocking direct sun; they also serve as small light shelves.
- Changes to glass transmittance, especially in the glare-producing upper window areas. Changes can be achieved by adding reflective or absorbing films or by reglazing.

Interior shades are less energy efficient and do not produce as high-performance indoor environmental quality because

- the heat absorbed by the shades is already trapped within the conditioned volume of the building and requires extra air conditioning energy to remove it,
- daylight harvesting measures such as dimmable lights are abrogated because when shades are pulled down they tend to stay down, and
- views are blocked when the shades are down.

Provide Separate Humidity Control

Many buildings are being maintained at 50% relative humidity or less. This has significant impacts on energy for dehumidification. However, such low limits are not supported by comfort requirements. Standard 55 does not impose upper limits for this reason. In general, at normal room air temperature, humidity up to 80% can be acceptable for thermal comfort (Fountain et al. 1999; Tsutsumi et al. 2007; Toftum et al. 1998).

In addition, indoor space temperatures are often driven by humidity control since space thermal loads and outdoor air dehumidification are being handled by the same cooling coil, resulting in overcooled spaces in summer. Installing separate dehumidification of outdoor air (with or without dedicated outdoor air) is a best practice for comfort and energy.

Report Results—Documentation for Advanced HVAC Commissioning

Records should be made of actions taken and of their anticipated comfort and energy outcomes. Such records can be used to guide building operators in the future, and their predictions can be compared to the results of post-action surveys, walk-through observations, and/or monitoring to determine whether adjustment or further measures are necessary.

TOOLS AND AIDS

Most of the analyses at the Advanced Analysis level may be supported by building energy simulation. The EnergyPlus program (EERE 2012) is capable of simulating the operation of mechanical systems under a range of thermostat dead bands and VAV airflow minima. It provides for autosizing the system as well, but this feature must be disabled when estimating the energy savings of setpoint changes within an existing plant. EnergyPlus is also capable of simulating surface temperatures within a room with solar gain and/or with radiant heating and cool-

TO THE COMMISSIONING TEAM

Sidebar should go near the documentation section of Thermal Comfort in Chapter 4.

The documentation recommended for thermal comfort applies to all other IEQ categories. Records of corrective actions taken, as well as of their effectiveness in improving performance, apply directly to the implementation, hand-off, and ongoing Cx phases by facilitating pre- and post-correction performance measurements conducted by the CxA.

ing systems, and it has a simplified model of indoor air motion resulting from window openings (Carrilho da Graca and Linden 2002).

Fans are usually selected and spaced based on simplified empirical data and rules of thumb on spacing and coverage. For simulating fan-driven airflows within a room, computational fluid dynamics (CFD) would be required, but it may be difficult to implement for ceiling fans because manufacturers' literature usually does not provide the required fan flow characteristics data.

The *ASHRAE Thermal Comfort Tool* (1997) is used to predict comfort under the Predicted Mean Vote model and the Adaptive Model and to estimate the effects of air movement cooling on occupants, as specified in ASHRAE Standard 55 (2010b).

IEQ INDOOR AIR QUALITY

Methods and measures for Advanced Analysis of IEQ indoor air quality should be implemented with the help of an IAQ professional. These topics are beyond the basics and are intended for use when there are special problems or when it is desired for operating methods that exceed those of a typical facility.

INTRODUCTION

At the Advanced Analysis level, measurements and analytical methods are applied to assess and evaluate IAQ problems or potential problems that have been identified at the other levels. Here potential contaminants of concern (CoC) in the indoor air are diagnosed and remediated as needed. An appropriate IAQ specialist will be aware of the complexities and challenges inherent in addressing suspected CoC. Environmental monitoring involves instrumented measurements that should be attempted only if contaminants are known or suspected and if there is a clear plan regarding what will be done with the results. The procedures for addressing these issues and contaminants are outlined in the Figure 4-11 flowchart.

PERFORMANCE MEASUREMENT PROCEDURE

Selecting an IAQ Specialist

Factors to consider for indoor chemistry measurement baseline and analysis and for indoor biocontaminant measurement baseline and analysis are presented in the sections that follow. An IAQ specialist should be prepared to address these factors. It is important to be aware of specialists' training and competency as well as any biases they may have based on their particular backgrounds.

Indoor Environmental Monitoring Baseline and Analysis

If Basic Evaluation or Diagnostic Measurement evaluations indicate that further study is needed, it will probably take the services of an industrial hygienist to provide the needed measurements. If mold was identified at the Basic Evaluation or Diagnostic Measurement levels, a firm that specializes in mold diagnostics and remediation should be hired. If there are nonobvious sources of odors, or if occupant complaints are recorded that could indicate sick building syndrome (SBS) or multiple chemical sensitivity (MCS), then a firm that specializes in IAQ investigations should be retained. If other nonobvious air movement or pressurization problems were detected that are not simply addressed, a firm that specializes in air-side diagnostics and/or duct cleaning may be needed.

Contaminant Measurement and Evaluation

This section provides building management with an understanding of the complexities involved in contaminant measurement and evaluation. Additional details can be found in Appendix H of this Guide, including text reproduced from Appendix A of *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* (ASHRAE 2009a). Note that in that appendix the term *monitoring* implies that instrumented measurements are being made.

When developing the measurement and analysis plan, the professional should consider several factors, including why the evaluation is being done, what contaminant are to be measured, what testing equipment and protocols should be used, the accuracy of the measurements, and what baseline will be used to evaluate the results. Where, when, and for how long the testing is conducted should also be included in the plan.

Unfortunately, there is no simple metric to measure a building's IAQ. Even experienced professionals can undertake monitoring that provides little or no useful information or that results in false or misleading conclusions. That is why it is so important to develop a plan with a clear purpose for the planned monitoring, specific target pollutants, and identified reference concentrations that will be used to interpret the results.

Spot measurements cannot accurately characterize a building's IAQ, so the plan should detail monitoring to be done over a range of time and operating conditions. In addition, because outdoor air ventilation rates heavily influence indoor-source pollutant concentrations, simultaneous measurement of ventilation should be included in the plan, and that data should be used when interpreting the results.

The characteristics of indoor air are described in more detail in Appendix A of *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* (ASHRAE 2009a), included in whole in Appendix H of this Guide. Specific key points from that text include the following:

- Indoor air is a complex mixture.
- Most indoor air pollutants are present at very low concentrations.
- Pollutant concentrations vary greatly within and between buildings.
- Humans can sense chemicals that cannot be detected by environmental monitoring.

Additional guidance on when and how to monitor IAQ is also addressed in the appendix. Specific key points covered include the following:

- Use environmental monitoring sparingly.
- Carefully consider where samples are taken.

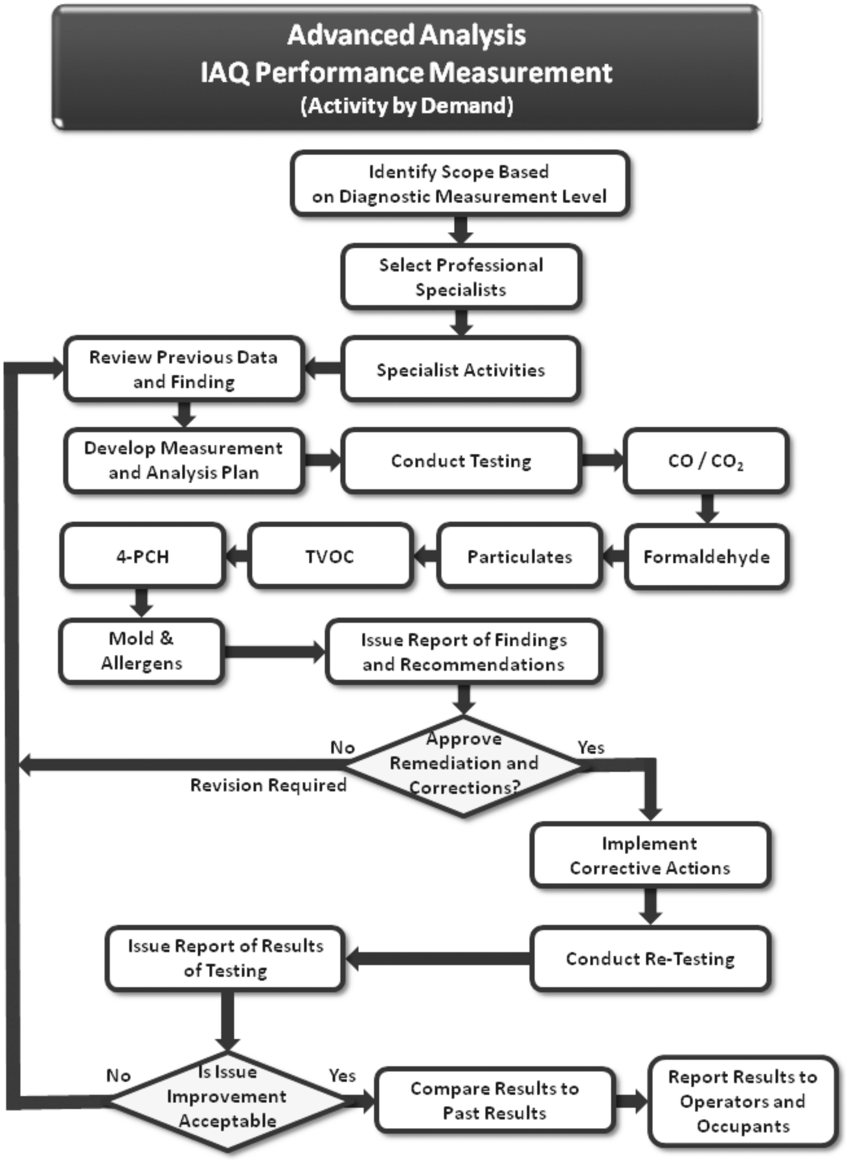


Figure 4-11 Indoor Air Quality Advanced Analysis Performance Measurement Procedures

- Consider source strength and ventilation when interpreting results.
- Sampling methods determine and limit what can be measured.

TOOLS AND AIDS

In addition to the above tools related to analysis of CoC, tools for airflow modeling also may be useful for Advanced Analysis.

Calibrated Airflow Models of a Building

There are situations where it is beneficial to have a detailed understanding of the airflows in a building to diagnose potential IAQ problems. In such cases it is possible to construct models with as much detail as is needed. These may first be developed at the time of construction or major renovation; however, there are also some potential uses for such models after there have been changes in physical lay-

Carbon Dioxide—The Most Measured Gas in Indoor Air

this comes directly from IAQ Guide. CITE.

Carbon dioxide (CO_2) is not a pollutant per se when measured at typical indoor concentrations. It is usually used as a surrogate for the adequacy of ventilation in relation to human occupancy. While the relationship between building ventilation rates and indoor CO_2 is well understood (Persily 1997; ASTM 2007a; Mudarri 1997), measurements of CO_2 in indoor air are commonly misapplied and misinterpreted. These references need to be consulted before conducting such measurements.

out or use of the building. At the time of EBCx, measurement sets may be needed to verify the adequacy of the model under as-built and as-operated conditions. The types of models and their uses are described in detail in Appendix H.

IEQ LIGHTING/DAYLIGHTING

INTRODUCTION

After the original IEQ lighting/daylighting checklist (Appendix A) has been prepared as part of Basic Evaluation and after the Diagnostic Measurement work has been completed, it is time to determine if there are any items remaining. Basic Evaluation items were those lighting and daylighting issues that could be resolved using in-house facilities and expertise. The Diagnostic Measurement procedures were more advanced and included a lighting audit and point-by-point lighting measurements performed by in-house personnel or outside services to determine if there were any areas requiring additional work at a higher level.

The recommendations of this section are intended to address these higher-level items. Advanced Analysis activities require the services of a professional with lighting/daylighting expertise. The first thing is to prepare a list of needs and then find a professional to resolve the issues.

PERFORMANCE MEASUREMENT PROCEDURE

The processes shown in the Figure 4-12 flowchart are discussed in detail in the text that follows. These steps are not necessarily strictly sequential but are presented in an order that will assist the user in determining if there are lighting quality issues and knowing how to proceed from there.

Review Walk-Through Checklist and Develop Improvement Plan

The plan should include the following steps:

- Review the Walk-Through Checklist (Appendix A) and list all items identified as requiring Advanced Analysis.
- Review Basic Evaluation items and items identified using Appendix A as requiring Diagnostic Measurement and determine which are unresolved.
- Prepare a list of all items that need to be addressed by the lighting professional.
- Hire a lighting professional to prepare a plan to resolve the outstanding items from the checklist.
    - Ask associates for a list of lighting professionals from past projects.

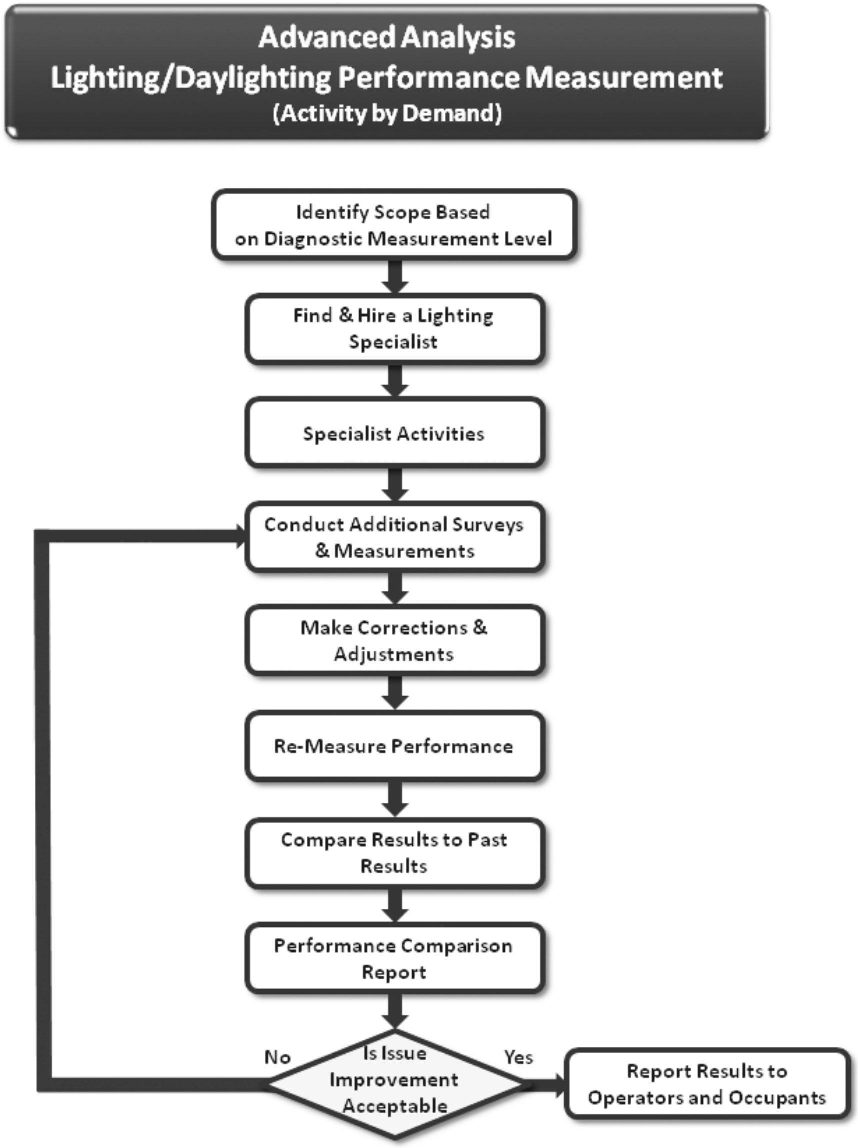


Figure 4-12 Lighting/Daylighting Advanced Analysis Performance Measurement Procedures

- Check other local resources for lists of lighting professionals they have used successfully.
- Contact professional organizations, such as the International Association of Lighting Designers (IALD, www.iald.org) or the National Lighting Bureau (NLB, www.nlb.org), for lighting professionals in the area that provide this type of service.
- Interview lighting professionals based on the list of items to be resolved and their methods of compensation for the services.

- Review the lighting professional's plan and budget and either authorize the procedure or have the lighting professional's plan revised based on company/organization input, then execute an agreement of services.

Conduct Additional Surveys and Measurements

For the lighting systems, performance measurement consists of surveying the building occupants regarding satisfaction with the lighting/daylighting and using the Walk-Through Checklist (Appendix A) for the portions of the building that have lighting issues.

The agreement of service should authorize the lighting professional to determine what additional measurements, testing, or survey methods are necessary to resolve the outstanding lighting and daylighting items. The lighting professional should include in this agreement the types of instruments that are to be used. Lighting instrumentation is discussed in Appendix I.

After the additional measurements, testing, and surveying have been conducted by the lighting professional, the results should be combined with an implementation plan to improve the outstanding items and with a budget for these actions. The areas that should be listed from the checklist and the improvement plan could include the following:

- Lighting and control
- Daylighting methods and controls
- Visual acuity
- Methods of measurement
- Energy use

Identify Issues Needing Action and Take Corrective Actions

The following steps should be taken to initiate appropriate action.

- Prepare a budget for Advanced Analysis work items and obtain permission to proceed.
- Assign appropriate personnel to work with the lighting professional to obtain cost estimates from contractors to conduct the work.
- Proceed with the corrective actions under the direction of the lighting professional.

Remeasure Performance

Follow up on the issues identified at the Advanced Analysis level with the following actions:

- Query occupants of all affected spaces to determine if corrective actions have improved the lighting and resolved the issues.
- Review the Walk-through Checklist to confirm that all Advanced Analysis items were either completed or omitted by agreement with the lighting professional.

Compare Results

On all items that appear to still be unresolved, meet with the lighting professional to determine why the items are unresolved and what actions are necessary to resolve them.

Report Results

The following items should be provided to management, the building operators, and all occupants:

- Actions taken
- Remeasurement results
- Anticipated benefits

TOOLS AND AIDS

Helpful tools and resources for Advanced Analysis of IEQ lighting/daylighting include the following:

- A complete list of all new lamps and ballasts specified by the lighting professional and installed as part of this work (this list can be included in the Proposed Luminaires table shown in Appendix I and included on the companion CD).
- A list of continuous-maintenance items necessary to maintain the areas that have been corrected, including revisiting the Walk-through Checklist (Appendix A) at regular intervals.
- An ongoing Cx procedure for the automatic control systems, including daylighting controls, for the most effective operation.

IEQ ACOUSTICS

INTRODUCTION

The Advanced Analysis level is required for IEQ acoustics in those situations where design and remediation are necessary but beyond the scope of the building operators, maintenance staff, or repair technicians. If the source of occupant dissatisfaction cannot be resolved by Basic Evaluation or Diagnostic Measurement corrective actions, then an acoustical consultant should be hired to determine the next steps.

PERFORMANCE MEASUREMENT PROCEDURE

The processes for Advanced Analysis of IEQ acoustics are shown in the Figure 4-13 flowchart and discussed in detail in the following subsections.

Hire an Acoustical Consultant

Lists of qualified consultants can be found on the Web sites of the Institute of Noise Control Engineering (INCE, www.inceusa.org) and the National Council of Acoustical Consultants (NCAC, www.ncac.com). Most acoustical consultants specialize in types of projects, such as mechanical systems or room acoustics. A professional engineering license is a plus.

The consultant should have a working knowledge of

- Chapter 48, Noise and Vibration Control, of the 2011 *ASHRAE Handbook—HVAC Applications* (2011c) and
- *Performance Measurement Protocols for Commercial Buildings* (ASHRAE 2010a).

The request for proposal to hire an acoustical consultant should include a description of the data collected to date and the expected deliverables. The consultant should respond with a statement of his or her qualifications and experience, a description of the anticipated scope of work, and an estimate of the expected fees.

Acoustical Consultant's Actions

The first task for the acoustical consultant is to review the data and findings of the Basic Evaluation occupant survey and, if conducted, the measurements of the Diagnostic Measurement level. The acoustical consultant will likely conduct a precise assessment of the background noise, in octave band sound pressure levels, and of the reverberation time in the rooms of interest with the objective of assess-

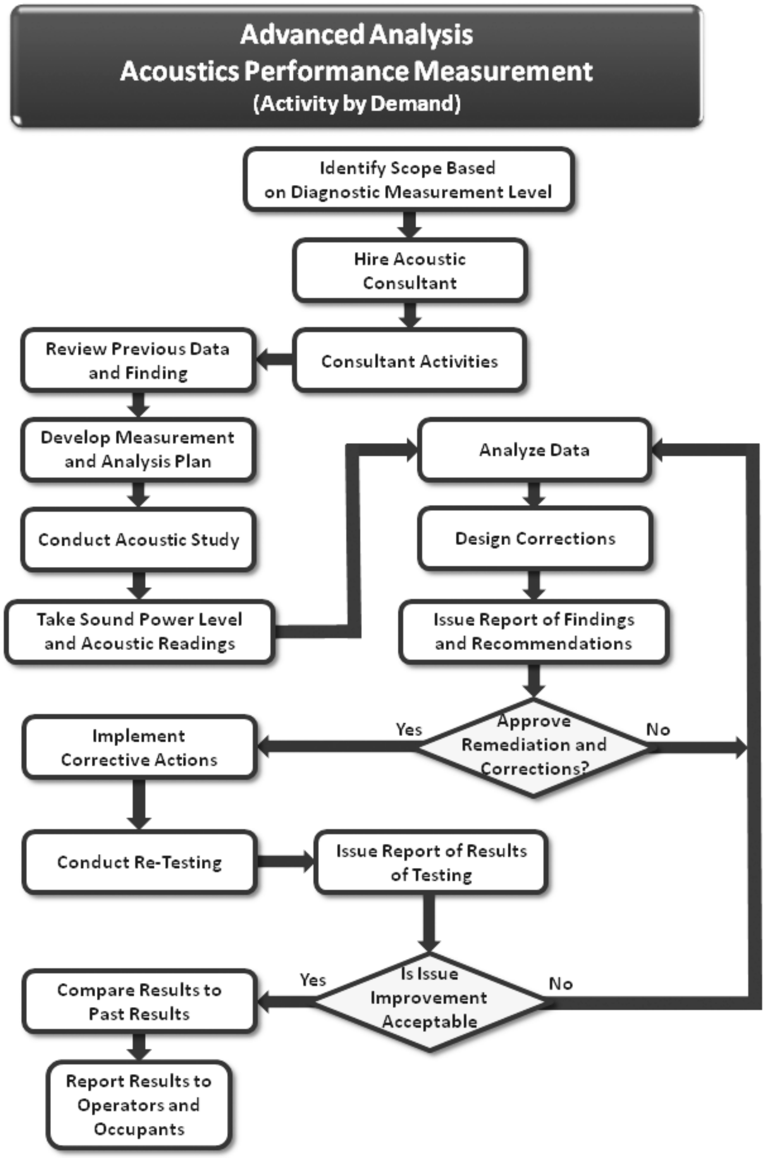


Figure 4-13 Acoustics Advanced Analysis Performance Measurement Procedures

ing acoustic annoyances that may affect study or work performance as well as speech and telephone communication, listening conditions, and privacy. Specifications and calibration requirements for octave band sound level meters are discussed in Appendix J. An example worksheet for recording octave band sound measurements is also shown in Appendix J and included on the companion CD.

If the character of the background sound includes unusual or distracting sounds, such as tones or time-varying amplitudes, the consultant may conduct other diagnostic tests such as narrow-band FFT spectral analysis or other fractional band measurements. Other advanced measurements may be conducted that assess sound and impact isolation from outside noise sources or adjacent rooms. The final objective of this work is to identify the root causes and quantify the sources of the occupants' dissatisfaction.

The consultant should recommend options to mitigate the sources of acoustic dissatisfaction, including estimated benefits and information from which costs can be derived. The consultant should then report the findings and recommendations. Recommendations will likely involve mechanical system and architectural design changes that require capital approval.

Make Corrections

Depending on the local building codes and regulations, implementation of the acoustical consultant's recommendations may also require the services of a mechanical engineer or architect. Final costs should be estimated by the appropriate professional who will implement the recommendations, such as the architect, mechanical engineer/contractor, or general contractor. During the project, the acoustical consultant should be retained to review the final design and construction/installation of the corrective actions.

Take Corrected Sound Readings

Follow-up sound pressure level measurements should be taken by the consultant to verify that the anticipated improvement was achieved. The Basic Evaluation occupant survey should also be repeated in the affected space to verify that occupant satisfaction has been achieved.

Compare to Previous Performance Measurements

Compare current measurements to previous measurements to determine if corrections have improved the issue to the satisfaction of the occupants.

Report Results

If Advanced Analysis corrective actions were taken, building operators and occupants should be made aware of the success of these actions in resolving sources of acoustic dissatisfaction. The report should indicate the sound pressure levels before and after the action was taken.

TOOLS AND AIDS

Appendix J includes an example of an Advanced Analysis level spreadsheet tool that is included on the attached CD.

Appendix A
Basic Evaluation General Forms Workbook

A

This appendix includes the forms that are found in the Basic Forms Workbook on the CD that accompanies this Guide. They are in Microsoft® Excel® and are fully accessible and editable. The forms include Basic Evaluation Measurement Plan, Building Characteristics, and Walk-Through Checklists for the Basic Evaluation procedures that list items to be addressed for energy, water, and the four IEQ categories of thermal comfort, IAQ, lighting/daylighting, and acoustics. The checklists identify the issues and whether they may directly and significantly affect costs It does not do this that I can see. and for each issue provides recommended corrective actions. The forms provide space to link each issue to a photo ID and to the building space in which the issue is observed.

BASIC EVALUATION MEASUREMENT PLAN FORM

Get form from Basic Evaluation General Forms Workbook

BASIC EVALUATION BUILDING CHARACTERISTICS FORM

Get form from Basic Evaluation General Forms Workbook

BASIC EVALUATION WALK-THROUGH CHECKLISTS AND RECOMMENDED CORRECTIVE ACTION FORMS

Get form from Basic Evaluation General Forms Workbook

Appendix B

Performance Measurement Report Template

B

Figure B-1 in this appendix includes the table of contents from a blank performance measurement report outline found in the Performance Measurement Report Template Microsoft® Word® file on the CD that accompanies this Guide. The report template can be used to summarize and report the information collected on the forms. The Word file on the CD is fully accessible and editable.

Performance Measurement Report
Table of Contents

ii

Figure B-1 Sample Table of Contents for a Performance Measurement Report

Appendix C

Occupant IEQ Survey

In deciding when corrective measures for IEQ thermal comfort are required, the Basic Evaluation level sets a limit of 20% dissatisfied as the threshold for action. This is somewhat arbitrary, coming from experience in the thermal comfort field. This 20% is the limit that ASHRAE Standard 55 (2010b) has adopted for acceptable thermal discomfort at any point in time. This is because it is practically impossible to have less thermal comfort dissatisfaction in uniformly conditioned buildings, since at the same indoor temperature some people are too hot and some are too cold.

With the Occupant Indoor Environmental Quality (IEQ) Survey™ at www.cbe.berkeley.edu/research/survey.htm (CBE 2008), typical dissatisfaction is more severe than the Standard 55 20% because in the survey we are integrating comfort satisfaction over time, and people have memories of discomfort events that can range back for months. Experience shows that if one includes satisfaction scores of 0 to +3 as representing satisfaction, the typical building's dissatisfaction score is about 40%. However, including the –1 score as satisfied gives a 20% dissatisfaction score in the same buildings.

Either the 20% or 40% limits may be used (together with their respective definitions of *satisfaction*). To make our comfort analysis understandable in the same terms as ASHRAE Standard 55, ~~we~~ include the –1 score as satisfied.

OCCUPANT IEQ SURVEY

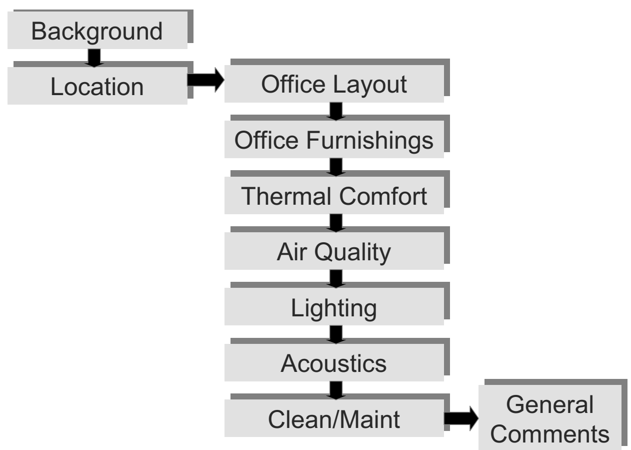
The Occupant IEQ Survey (CBE 2008) covers the four major categories of IEQ discussed in this Guide (thermal comfort, IAQ, lighting/daylighting, and acoustics) as well as information on the building, its design, and its operation. The CBE survey is used at the Basic Evaluation level for each of the four IEQ sections.

An alternative survey is the BUS survey (UBT 2008). Both the CBE and BUS surveys have large databases of accumulated results that serve as benchmarks against which occupants' responses can be evaluated.

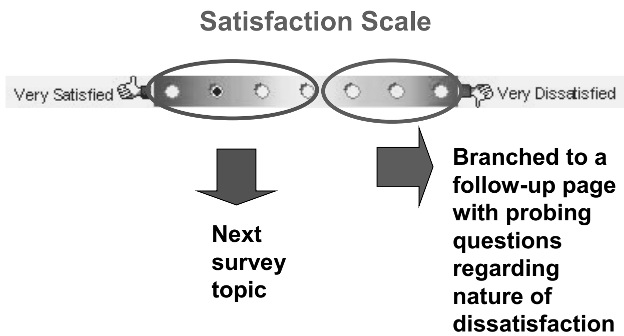
This appendix shows the screenshots that occupants would see while taking the CBE survey online. The CBE survey is reprinted with permission from Center for the Built Environment.

Prefatory notes to the survey that follows.

The core survey obtains background information and the occupants' evaluation of seven indoor environmental quality topics. A set of 'primary' questions is presented on a single page for each of the topics. There is also a 'follow-up' or 'branching' page for each topic that is used for diagnosing the cause of any dissatisfaction that the occupant may have indicated.



If a person votes on the 'satisfied' side of a survey question, there will be no follow-up questions for that topic. The pages starting with "You have said you are dissatisfied with…" are all branching pages and only appear to people who voted on the 'dissatisfied' side of that topic.



The number of screens seen by an individual respondent varies according to how much dissatisfaction he or she indicates. It is very rare for someone to see more than four branching pages, even though the list of all branching pages is long.

Finally, the 'Building Features' page (shown near the end of the survey) is not normally part of the CBE core survey, but is an optional module used in projects where building energy performance is being assessed.

Background

How many years have you worked in this building?

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-5 years
- ○ More than 5 years

How long have you been working at your present workspace?

- ○ Less than 3 months
- ○ 4-6 months
- ○ 7-12 months
- ○ More than 1 year

In a typical week, how many hours do you spend in your workspace?

- ○ 10 or less
- ○ 11-30
- ○ More than 30

How would you describe the work you do?

- ○ Administrative support
- ○ Technical
- ○ Professional
- ○ Managerial/supervisory
- ○ Other

What is your age?

- ○ 30 or under
- ○ 31-50
- ○ Over 50

What is your gender?

- ○ Female
- ○ Male

Continue

Survey Progress...

Personal Workspace Location

On which floor is your workspace located?

choose one

In which area of the building is your workspace located?

choose one

To which direction do the windows closest to your workspace face?

choose one

Are you near an exterior wall (within 15 feet)?

- ○ Yes
- ○ No

Are you near a window (within 15 feet)?

- ○ Yes
- ○ No

Continue

Survey Progress...

Personal Workspace Description

Which of the following best describes your personal workspace?

- ○ Enclosed office, private
- ○ Enclosed office, shared with other people
- ○ Cubicles with high partitions (about five or more feet high)
- ○ Cubicles with low partitions (lower than five feet high)
- ○ Workspace in open office with no partitions (just desks)
- ○ Other: ____________

Continue

Survey Progress...

Office Layout

How satisfied are you with the amount of space available for individual work and storage?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the level of visual privacy?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with ease of interaction with co-workers?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the office layout enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Please describe any other issues related to the office layout that are important to you.

Continue

Survey Progress...

Available Space

You have said that you are dissatisfied with the amount of space available for individual work and storage. Which of the following contribute to your dissatisfaction? (check all that apply)

- ☐ Amount of work surface area
- ☐ Total area of work station
- ☐ Available filing and storage space
- ☐ Available space for personal items
- ☐ Space for meeting with other people
- ☐ Other: ____________

Continue

Survey Progress...

Visual Privacy

You have said that you are dissatisfied with the level of visual privacy. Which of the following contribute to your dissatisfaction? (check all that apply)

- ☐ High density--too little space separating people
- ☐ Partitions or walls are too low or transparent
- ☐ People can easily see in through exterior windows
- ☐ Too many people walking in my work area
- ☐ Other: __________

Continue

Survey Progress...

Ease of Interaction

You have said that you are dissatisfied with the ease of interaction with co-workers. Which of the following contribute to your dissatisfaction? (check all that apply)

- ☐ My work station is not near my co-workers
- ☐ My work station is difficult to find or out of the way
- ☐ Conversations are discouraged because the noise is distracting to others
- ☐ There are no spaces (i.e., break rooms) to casually interact with co-workers
- ☐ There are few organized opportunities to interact with co-workers
- ☐ Other: __________

Continue

Survey Progress...

Office Furnishings

How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with your ability to adjust your furniture to meet your needs?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the colors and textures of flooring, furniture and surface finishes?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Do your office furnishings enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Please describe any other issues related to office furnishings that are important to you.

Continue

Survey Progress...

Thermal Comfort

Which of the following do you personally adjust or control in your workspace? (check all that apply)

- ☐ Window blinds or shades
- ☐ Operable window
- ☐ Thermostat
- ☐ Portable heater
- ☐ Permanent heater
- ☐ Room air-conditioning unit
- ☐ Portable fan
- ☐ Ceiling fan
- ☐ Adjustable air vent in wall or ceiling
- ☐ Adjustable floor air vent (diffuser)
- ☐ Door to interior space
- ☐ Door to exterior space
- ☐ None of the above
- ☐ Other: ________

How satisfied are you with the temperature in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does your thermal comfort in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Continue

Survey Progress...

Temperature

You have said that you are dissatisfied with the temperature in your workspace. Which of the following contribute to your dissatisfaction?

In warm/hot weather, the temperature in my workspace is: (check all that apply)

- ☐ Often too hot
- ☐ Often too cold

In cool/cold weather, the temperature in my workspace is: (check all that apply)

- ☐ Often too hot
- ☐ Often too cold

When is this most often a problem? (check all that apply)

- ☐ Morning (before 11am)
- ☐ Mid-day (11am - 2pm)
- ☐ Afternoon (2pm - 5pm)
- ☐ Evening (after 5pm)
- ☐ Weekends/holidays
- ☐ Monday mornings
- ☐ No particular time
- ☐ Other: ______

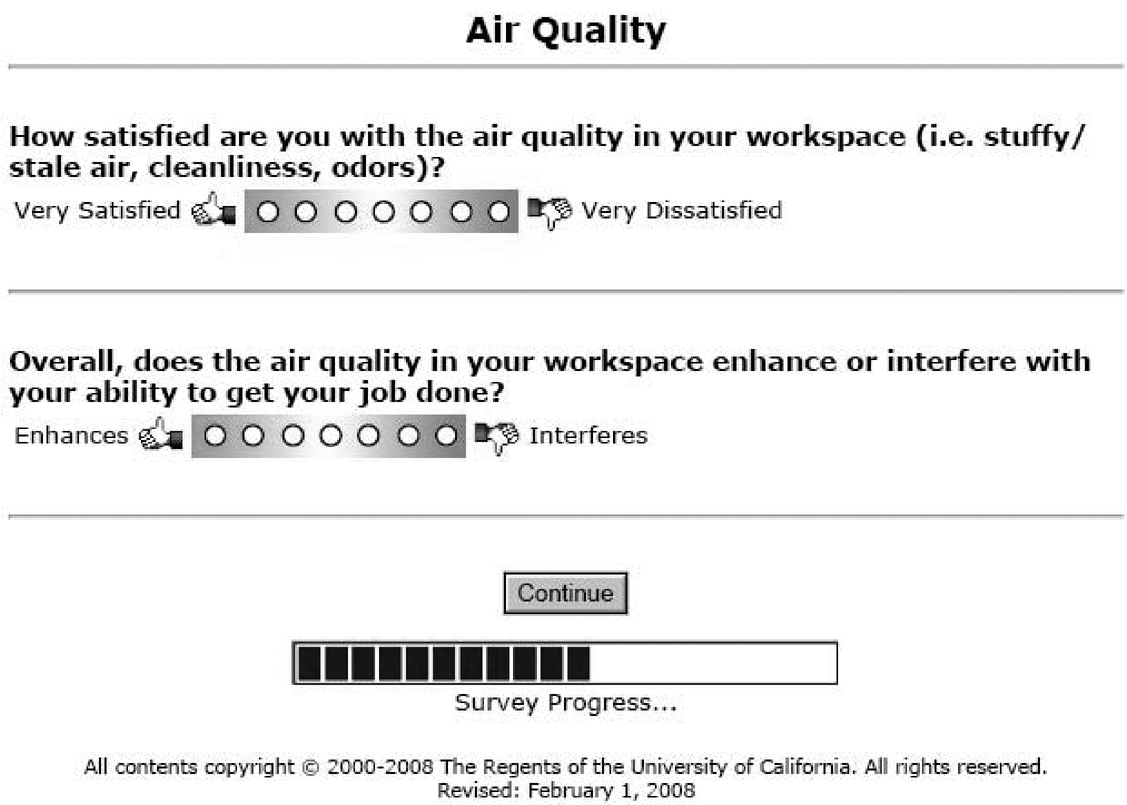
How would you best describe the source of this discomfort? (check all that apply)

- ☐ Humidity too high (damp)
- ☐ Humidity too low (dry)
- ☐ Air movement too high
- ☐ Air movement too low
- ☐ Incoming sun
- ☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)
- ☐ Heat from office equipment
- ☐ Drafts from windows
- ☐ Drafts from vents
- ☐ My area is hotter/colder than other areas
- ☐ Thermostat is inaccessible
- ☐ Thermostat is adjusted by other people
- ☐ Heating/cooling system does not respond quickly enough to the thermostat
- ☐ Clothing policy is not flexible
- ☐ Other: ______

Please describe any other issues related to being too hot or too cold in your workspace.

Continue

Survey Progress...



Air Quality

How satisfied are you with the air quality in your workspace (i.e. stuffy/ stale air, cleanliness, odors)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Continue

Survey Progress...

Revised: February 1, 2008

Air Quality (continued)

You have said that you are dissatisfied with the air quality in your workspace. Please rate the level of each of the following problems:

Air is stuffy/stale

Minor problem ○ ○ ○ ○ ○ ○ ○ Major problem

○ **Not a problem**

Air is not clean

Minor problem ○ ○ ○ ○ ○ ○ ○ Major problem

○ **Not a problem**

Air smells bad (odors)

Minor problem ○ ○ ○ ○ ○ ○ ○ Major problem

○ **Not a problem**

If there is an odor problem, which of the following contribute to this problem? (check all that apply)

- ☐ Tobacco smoke
- ☐ Photocopiers
- ☐ Printers
- ☐ Food
- ☐ Carpet or furniture
- ☐ Other people
- ☐ Perfume
- ☐ Cleaning products
- ☐ Outside sources (car exhaust, smog)
- ☐ Other: ____________

Please describe any other issues related to the air quality in your workspace that are important to you.

Continue

Survey Progress...

Lighting

Which of the following controls do you have over the lighting in your workspace? (check all that apply)

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds or shades
- ☐ Desk (task) light
- ☐ None of the above
- ☐ Other: ______

How satisfied are you with the amount of light in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the lighting quality enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Continue

Survey Progress...

Lighting (continued)

You have said that you are dissatisfied with the lighting in your workspace. Which of the following contribute to your dissatisfaction? **(check all that apply)**

- ☐ Too dark
- ☐ Too bright
- ☐ Not enough daylight
- ☐ Too much daylight
- ☐ Not enough electric lighting
- ☐ Too much electric lighting
- ☐ Electric lighting flickers
- ☐ Electric lighting is an undesirable color
- ☐ No task lighting
- ☐ Reflections in the computer screen
- ☐ Shadows on the workspace
- ☐ Other: ______

Please describe any other issues related to lighting that are important to you.

Continue

Survey Progress...

Acoustic Quality

How satisfied are you with the noise level in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the acoustic quality in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Continue

Survey Progress...

Acoustic Quality (continued)

You have said you are dissatisfied with the acoustics in your workspace. Which of the following contribute to this problem? (check all that apply)

- ☐ People talking on the phone
- ☐ People talking in neighboring areas
- ☐ People overhearing my private conversations
- ☐ Office equipment noise
- ☐ Office lighting noise
- ☐ Telephones ringing
- ☐ Mechanical (heating, cooling and ventilation systems) noise
- ☐ Excessive echoing of voices or other sounds
- ☐ Outdoor traffic noise
- ☐ Other outdoor noise
- ☐ Other: __________

Please describe any other issues related to acoustics that are important to you.

Continue

Survey Progress...

Building Features

Considering energy use, how efficiently is this building performing in your opinion?

Very energy efficient ○ ○ ○ ○ ○ ○ ○ Not at all energy efficient

Comments:

Please note that the list provided here is for demo purposes only, a maximum of four building features will be included on this page as part of a standard survey.

For each of the building features listed below, please indicate how satisfied you are with the effectiveness of that feature:

Floor air vents

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Thermostats

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Light switches

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Automatic daylight controls

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Occupancy sensors for lighting

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Window blinds

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Roller shades

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Exterior shades

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Low flow faucets

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Private meeting rooms

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

Security system

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

○ **I have no experience with it**

Comments:

How well informed do you feel about using the above mentioned features in this building?

Very well informed ○ ○ ○ ○ ○ ○ ○ Not well informed

Please describe any other issues related to the design and operation of the above mentioned features that are important to you.

Continue

Survey Progress...

General Comments

All things considered, how satisfied are you with your personal workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness):

Increased	○ 20%	○ 10%	○ 5%	○ 0%	○ -5%	○ -10%	○ -20%	Decreased

How satisfied are you with the building overall?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Any additional comments or recommendations about your personal workspace or building overall?

Thank you for participating in this Survey!

Exit

Appendix D
Energy Verification Workbooks

This appendix includes forms that are found in the Basic Evaluation Electrical Energy Verification Workbook and the Diagnostic Measurement Electrical Energy Verification Workbook included on the CD accompanying this Guide. The forms and charts are in Microsoft® Excel® spreadsheets that are fully accessible and editable. The forms include the Utility Bill Data Input Form, Prior Year or Baseline Data Input Form, Energy Use Charts, Energy Cost Charts. Instructions tabs in each form provide information on how to fill out the forms. The charts are automatically populated based on the data entered into the worksheets. Examples of the data input form and the charts are shown in this appendix.

This appendix also includes forms that are found in the Whole-Building Energy and Weather Data Normalization Workbook included on the CD accompanying this Guide. This workbook provides normalization forms for both electricity and natural gas. These charts are also discussed in the energy section of Chapter 3.

BASIC EVALUATION DATA INPUT FORM EXAMPLE

This is the Current Utility Data worksheet in the excel filename: Level 1 Electrical Energy Verification Worksheets 12-31-10 R1.xlsx

BASIC EVALUATION CHART EXAMPLES

These are the Electrical Use and Electric Cost Charts worksheets in the excel filename: Level 1 Electrical Energy Verification Worksheets 12-31-10 R1.xlsx

ENERGY NORMALIZATION INPUT FORM EXAMPLE

This is the Electric Usage & Weather Data worksheet from the Whole Building Energy & Weather Data Normalization Example.xlsx workbook.

ENERGY NORMALIZATION CHART EXAMPLE

This is the Electric Usage vs CDD worksheet from the Whole Building Energy & Weather Data Normalization Example.xlsx workbook.

Appendix E
Energy Advanced Analysis Examples

The best way to illustrate the key analysis concepts communicated in the energy section of the Advanced Analysis chapter of this Guide is through examples. Therefore, two examples are included in this appendix. These examples as well as five additional examples are included on the CD accompanying this Guide; all seven examples are described in Table E-1. All of the examples focus on the collection and graphical analysis of interval trend data from building energy systems. All of the examples also focus on improving the operation of existing equipment, mostly by turning it down or off where possible. These examples show what is possible through analysis of the increasingly large amount of data available from buildings.

Table E-1 Energy Advanced Analysis Examples

No.	Building Type	Application	Key Point
1	Small commercial office building #1	Review of small split direct-expansion (DX) system operation	Maintenance leads to energy savings.
2	Large university research laboratory building	Review of measured steam loads versus building energy model predictions	Comparison of actual data versus building energy model (BEM) data is useful for diagnosing building energy performance.
3	Large state government office building #1	Review of air-handling unit (AHU) and lighting systems operation	Changes to programmed schedules result in substantial energy savings.
4	Large state government office building #2	Review of water-source heat pump (WSHP) loop pump operation	Change to programmed setpoint results in substantial energy savings.
5	Large state government office building #2	Review of operation of dedicated outdoor air system (DOAS) with energy recovery	Changes to programmed schedule and setpoint result in substantial energy savings.
6	Small higher education teaching facility	Review of pre-retrofit and post-retrofit variable-air-volume (VAV) terminal operation and building energy performance for an energy retrofit project	Adding low-cost occupancy sensors to control VAV terminals (when schedules are difficult to program) results in substantial energy savings.
7	Small commercial office building #2	Review of 75 ton packaged rooftop unit (PRTU) economizer operation	Changing out a faulty equipment controls sensor results in energy savings.

All examples for this appendix were developed using the *Universal Translator* (the UT), a free program available from the The Pacific Energy Center (PEC 2012). However, as stated in the energy section of the Advanced Analysis chapter of this Guide, there are other programs available in the market that can be used to perform similar evaluations. Some of these programs include features such as connecting directly with building energy management systems to obtain data (i.e., automated data collection), while others can automate the diagnosis and reporting of fault conditions. These types of programs can provide value and are therefore recommended to be explored.

The reason the UT was used to develop these examples is primarily because it is free and is therefore accessible to anybody wanting to use it, regardless of available funds. The UT does involve the significant additional manual step of collecting the data and then importing into the program. However, the UT contains features to make this work as productive as possible. Then, once the data is in the program, the UT includes significant data processing, analysis, and charting capabilities that can be of great use to energy engineers, commissioning authorities, retro-ommissioning practitioners, energy auditors, measurement and verification (M&V) practitioners, utility energy incentive program managers, etc. Future upgrades to the program are anticipated to include fault diagnostic modules and M&V analysis modules, among other things. In its current form, the UT offers at least the following four major benefits:

- The ability to synchronize multiple interval data streams with disparate recording time intervals to common time intervals (i.e., to synchronize data).
- The ability to work with data from both stand-alone data-logging equipment and building automation/energy management systems.
- The ability to create stacked time series charts (i.e., multiple panes) from interval data, which shows the behavior of multiple system variables over time. This type of chart is a very useful diagnostic tool; it is illustrated in examples 1 and 3–7.
- The ability to create X-Y scatter charts from interval data, which commonly include an energy variable (i.e., kilowatt-hours, ton-hours, pounds of steam per hour, etc.) versus outdoor air temperature. This type of chart can also be a very useful diagnostic tool; it is illustrated in example 2.

Although there is increasing focus on automated fault detection and diagnostic tools, which certainly have merit, these examples assume the individual evaluating the data *is* the fault detection and diagnostic tool.

Before getting to the examples, we should note that we have deliberately tried to be careful to not make this area so complicated that few people attempt to tackle it. The approach illustrated by these examples is simply to get data, chart them, and evaluate them. We believe that this simple approach will actually be quite successful. Once the appropriate time series and X-Y charts are created, we believe that the problems and the recommended corrective actions will become obvious to practitioners.

EXAMPLE 1—REVIEW OF SMALL, SPLIT DX SYSTEM FOR SMALL COMMERCIAL OFFICE BUILDING

KEY POINT

Performing maintenance on existing HVAC equipment can result in energy savings.

OVERVIEW

A small commercial office building tenant is experiencing high energy costs and comfort issues. The tenant has requested an investigation by the owner. The tenant's space is served by a small split DX HVAC system. The tenant has complained that she has set the thermostat to 75°F to be energy efficient and reduce unit runtime and energy usage. However, the unit continues to run a lot during the day, yet it cannot keep the space at 75°F. Instead, the space is getting warmer than the setpoint. The owner hires an energy auditor to install data loggers to monitor the outdoor temperature, the room temperature, and HVAC system operation (i.e., unit runtime).

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The scope of the analysis is the HVAC system. The energy auditor installs the data loggers and monitors the outdoor temperature, room temperature, and HVAC operation from 6/21/2010 through 6/24/2010. The auditor produced Figure E-1 with the data collected from the data loggers. The observations that follow are based on this chart. This chart, generated using the UT software, captures the essential elements of the HVAC system operation necessary for this investigation.

OBSERVATIONS

The auditor observes that when it gets hot outside (i.e., when the outdoor air temperature [OAT] is >90°F) the system runtime increases significantly. However, the system runtime decreases at night during cooler periods. The auditor suspects the unit is low on refrigerant because the unit's runtime is 100% when OAT is > 80°F yet it cannot meet the desired setpoint of 75°F. The auditor knows the unit has not nearly run out of refrigerant, because if it had the unit runtime would be 100% (or close) all the time. This confirms the comfort issues experienced by the tenant. The OAT is not that hot (in the low to mid-90s) such that the system should be keeping up. If the unit is low on refrigerant, this is wasting energy because the unit is running nearly 100% during the day trying to meet a setpoint that it cannot meet. If the unit cannot keep up when the OAT is ≤95°F, what will happen when it is 105°F outside?

Finally, the auditor notices that the room temperature is being satisfied after hours when it is cooler outside. However, the system runtime is still a fair amount because the space temperature setpoint is not being reset via a programmable thermostat.

RECOMMENDED CORRECTIVE ACTIONS

To increase system performance, improve comfort conditions, and increase the energy efficiency of the system, the auditor recommends the owner pay for a tune-up of the system, including ensuring the unit has the proper amount of refrigerant. The owner implements this recommendation. The unit is found to be low on refrigerant. The system tune-up utilizes best-practice commercial ai-conditioning systems electronic diagnostic and measurement tools. This results in the addition of refrigerant to bring the overall refrigerant level to the exact level required by the manufacturer, resulting in increased performance and efficiency. The unit will now be able to maintain the space temperature at 75°F.

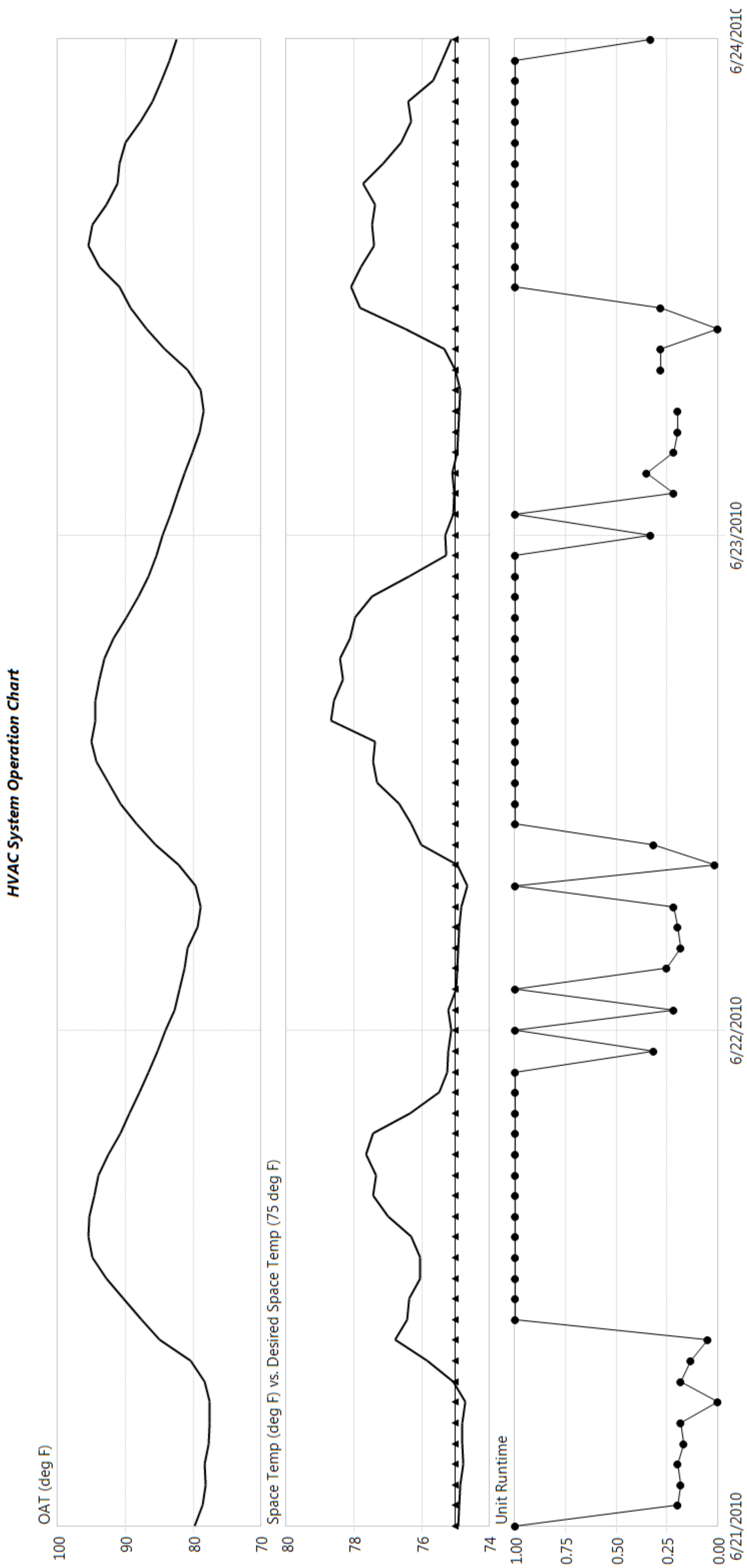


Figure E-1 HVAC System Operation Chart (Example 1)

The auditor also recommends replacing the existing thermostat with a programmable thermostat for automatically resetting the cooling space temperature setpoint higher during unoccupied hours. The owner implements this recommendation as well. The unit will now run less to meet the desired setpoint of 75°F during occupied hours. During unoccupied hours, the unit will also run less due to automatic thermostat setpoint reset to 82°F.

The tenant can now have both increased comfort and lower energy costs. Consequently, the tenant is satisfied that the building owner has addressed her concerns.

EXAMPLE 2—REVIEW OF ACTUAL STEAM LOADS VERSUS BUILDING ENERGY MODEL PREDICTIONS FOR LARGE UNIVERSITY RESEARCH LABORATORY BUILDING

KEY POINT

Building energy models (BEM) can be very useful for comparing and diagnosing actual energy data by adding perspective to the data and functioning as self-reference performance-comparison benchmarks.

OVERVIEW

A university research building has multiple air-handling units (AHUs) that are providing chilled water from the university district cooling system. The AHUs serve multiple variable-air-volume (VAV) terminals located throughout the building that are equipped for heating and reheating with hot-water coils. The hot water is provided by a steam-to-hot-water converter and the campus district heating system. A recent project focused on improving the energy performance of the building, and a key focus was on reducing the minimum airflow setpoints on the VAV terminals. Reducing the VAV minimum airflows can be accomplished by scheduling or through occupancy sensors, either of which can reset minimum cooling airflow setpoints to 0 cfm during unoccupied hours. This allows the VAV terminals to go completely closed during unoccupied hours and only open if the zone required heating or cooling. The project work was therefore expected to result in significant energy savings, mainly through the reduction of simultaneous cooling and heating between the AHUs and the VAV terminals. Previously, the minimum cooling airflow setpoints were not reset.

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The university records multiple data points for monitoring building energy performance, including hourly steam load (lb/h) and hourly ambient OAT. In addition, building energy models were developed as part of the project development and ongoing M&V phases.

Significant steam energy savings were expected due to the energy retrofit work. Consequently, the energy engineer would like to review the actual measured building steam loads and how they compare to estimated performance in order to verify savings. The energy engineer decides that a great way to analyze the steam loads is to graph the daily average hourly steam load (lb/h) versus the daily average hourly OAT. However, in order to better understand the actual steam loads data, the energy engineer wants to also compare actual performance to predicted performance data from the energy models. Various predictions are available from the building energy models, including the baseline scenario, the post-retrofit best-case scenario, and the post-retrofit worst-case scenario. The baseline scenario shows estimated performance of the building with no energy retrofit work performed. The post-retrofit best-case scenario shows the performance of the building if everything anticipated for the energy retrofit modifications works as planned or as intended. The post-retrofit worst-case scenario is an extreme case to show what the building performance would be like if all VAV terminals were somehow modified to constant-volume operation. Figure E-2 shows all four of these scenarios on an XY scatter chart.

OBSERVATIONS

With regards to Figure E-2, the actual performance is shown in orange while the best-case estimated performance is blue, the worst-case estimated performance is red, and the baseline estimated performance is green.

Figure E-2 shows some very interesting information. At a high level, we can see that the building is performing better than the baseline and far better than the worst-case scenario, both of which are great news. We can see that the energy retrofit modifications are clearly working to significantly reduce the average hourly steam load below the baseline performance level, just not to the best-case level. That's all right, because at least now we know, and because we know we can do something about it. The big difference appears to be in the base load. When the OAT is greater than 60°F, we estimate an average base steam load of approximately 500 lb/h, based on the retrofit work. However, the actual data shows that the average base steam load is closer to 1000 lb/h when the OAT is great than 60°F. This indicates that perhaps the VAV minimum airflow setpoints are not resetting back as much as we had hoped. Consequently, Figure E-2 leads us to the direction we need to go in.

RECOMMENDED CORRECTIVE ACTIONS

The data in Figure E-2 suggests that the team should go back and focus on VAV minimum airflow setpoints. The recommended corrective action is to engage in a detailed review of the programmed VAV terminal airflow setpoints and trend data of actual VAV terminal operation. The goal is to locate any VAV terminals that should have their minimum airflows reset but for whatever reason have not. That information should lead to identifying additional corrective actions to remedy.

ADDITIONAL DISCUSSION

With regards to building energy models, we believe Figure E-2 shows the value they can provide. Some people believe it is too difficult to model actual building operation so there is no point in trying. However, we believe it is worth trying. It is actually pretty straightforward to model the best-case and worst-case performance scenarios. The best-case performance for a project, for example, can be based on an energy modeling procedure for a building rating method, such as the ANSI/ASHRAE/IESNA Standard 90.1-2007 Appendix G Performance Rating Method (2007c). This specific procedure is highly idealized in that it assumes perfect building operation (i.e., that the equipment is scheduled off or heavily reset during unoccupied periods, etc.). But, similar to the best-case scenario in Figure E-2, this still gives us a target to shoot for, which is better than having no target at all. In addition, it is pretty easy to remove all the idealized assumptions from the best-case energy model regarding building operation. What you are left with is an estimate for the worst-case operation. In the real world, VAV terminals are overridden to constant-air-volume operation. Schedules are overridden and

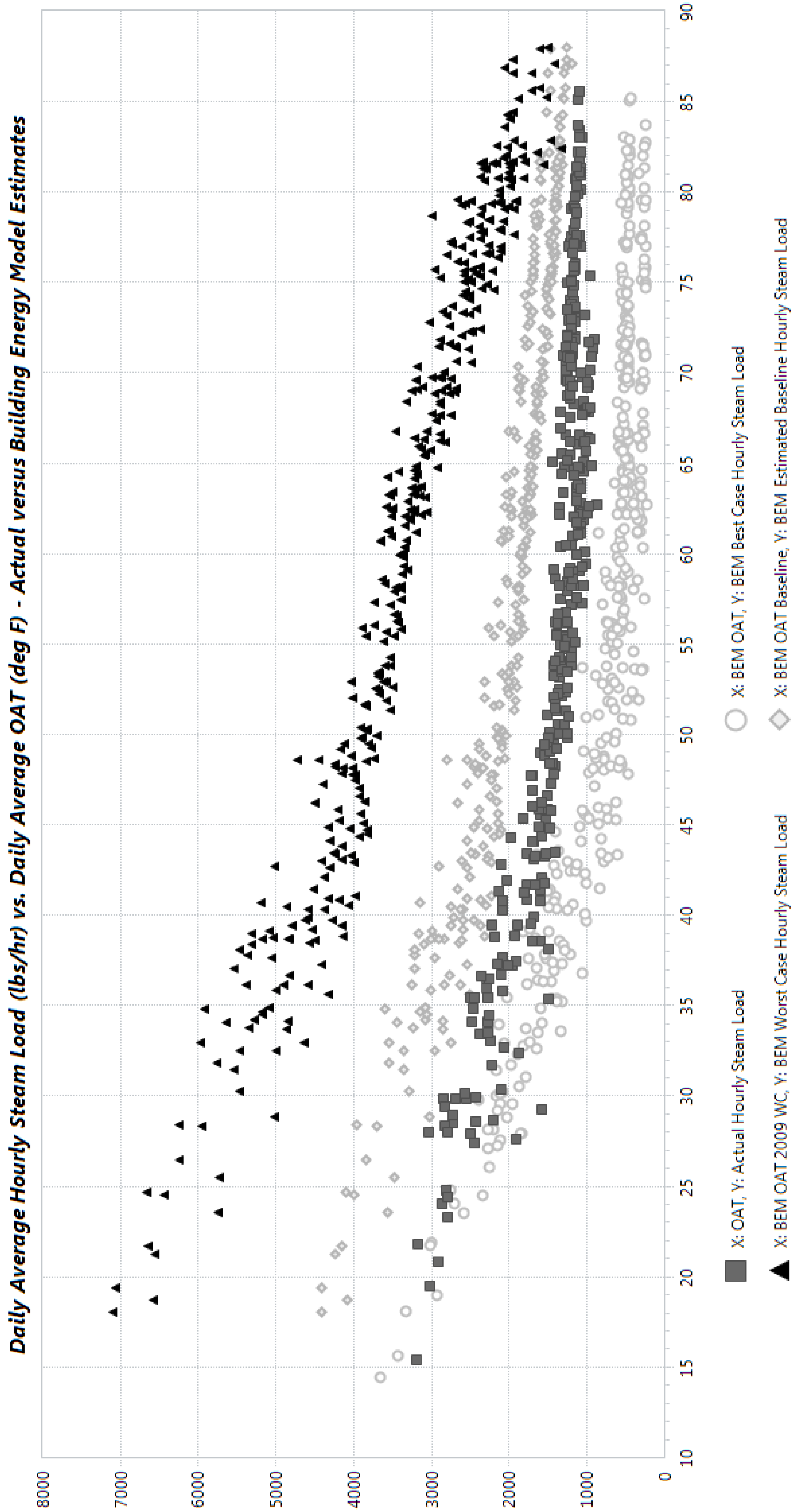


Figure E-2 Daily Average Hourly Steam vs. Daily Average OAT (Example 2) setpoints are adjusted. The energy engineer can account for these items in the development of the worst-case scenario. Comparing actual performance to best-case and worst-case estimated performance quickly tells us how the building is operating. In this case, Figure E-2 shows energy savings are occurring and the building is operating pretty well. But, the chart also shows there is additional work to be done, hence the value of this type of chart.

EXAMPLE 3—REVIEW OF AHU AND LIGHTING SYSTEMS SCHEDULED OPERATION FOR LARGE STATE GOVERNMENT OFFICE BUILDING

KEY POINT

Simple changes to schedules programmed in the energy management and control system (EMCS) can lead to significant energy savings.

OVERVIEW

The facility manager for a large state government office building believes the energy consumption of his building is higher than it should be and therefore requests an evaluation of the building AHU and lighting systems to determine if they are operating as intended to keep energy consumption and costs to a minimum.

AHU System

The majority of the building (office tower) is primarily served by two large 50,000 cfm AHUs whose ducts are interconnected throughout the building such that in essence the AHUs operate as a single AHU system. In addition, an outdoor energy recovery unit (ERU) provides preconditioned outdoor air (10,000 cfm minimum to 14,000 cfm maximum) to the AHUs via outdoor-air VAV terminals that serve each AHU. The kilowatt usage of the two supply fans of the main AHUs and the ERU outdoor air and exhaust air fans is monitored via the variable-frequency drives (VFDs) that control the fans. The power data is recorded in the building EMCS. The peak power for all four of these fans is estimated to be, from the original project documents, ~132 kW.

Lighting Systems

The office building is six floors and ~122,500 gross ft^2, while the total interior lighted area is closer to 107,000 ft^2. The building has typical 8:00 a.m. to 5:00 p.m. Monday–Friday operation. The peak building lighting power was estimated by the original project energy engineer to be ~96 kW (i.e., ~0.9 W/ft^2) based on design documents, lighting equipment submittals, etc. The building has a large exterior glass exposure and therefore includes daylight harvesting lighting controls. In addition, the building has occupancy-sensor lighting controls in nearly all of the rooms throughout the building. Because of the large glass exposure and because all rooms of the building are not occupied simultaneously by the building occupants, we would not expect the total building lighting power during occupied hours to be close to the 96 kW maximum value if the occupancy sensor and daylight harvesting lighting controls are functioning as intended. In addition, the majority of the building lighting is tied into lighting control panels that are programmed and therefore expected to turn the lighting off during unoccupied hours. Finally, the building has advanced metering included and tied into the EMCS.

This includes six power meters installed for the six building lighting electrical panels (one for each floor).

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The primary focus of the analysis (i.e., the scope) is determined to be reviewing the AHU and lighting systems operation versus time to verify that the equipment is turning off at nights and on weekends as the facility manager believes they should be.

To investigate the AHU and lighting systems operating schedules performance, the energy engineer obtains trend data on the four fans referenced previously and on the six main lighting power meters, all of which is available at five-minute intervals via the EMCS. The energy engineer collects this data and imports into the UT software (PEC 2012) and then creates a variable called *Total AHU Fan Power* by adding up all four VFD power trends in the program and a variable called *Total Building Lighting Power* by adding up all six lighting power meter trends in the program.

The energy engineer then creates the chart shown in Figure E-3, which covers the time period of 8/4/2008 through 8/11/2008. This chart shows both *Total AHU Fan Power* and *Total Building Lighting Power* versus time. The observations that follow are based on this chart. This chart is used by the energy engineer to communicate the performance of the AHU and lighting systems to the facilities manager. This chart leads to the development of a corrective actions plan. The plan is implemented and the post-retrofit performance is verified through the development of the chart shown in Figure E-4, which covers the time period of 8/10/2009 through 8/17/2009 (i.e., the post-retrofit period). It is important to perform ongoing review of retrofit work to ensure it continues to achieve the energy reduction goals. Consequently, Figure E-5 is developed that covers the period of 6/13/2011 through 6/20/2011. The energy engineer believes that these charts capture the important characteristics of the building AHU and lighting systems operation in an appropriate level of detail desired by the facilities manager.

OBSERVATIONS

The following observations are made based on the charts included in Figures E-3 through E-5:

- Figure E-3 shows the AHUs are using less fan power during nights and weekends but are not scheduled to be completely off. In addition, curiously, there is a 25 kW base load at nights and on weekends during the hours of ~6:00 p.m. to 6:00 a.m.
- Figure E-3 shows significant weekend usage during the hours of 6:00 p.m. to 6:00 a.m., which is a time period when the building is not occupied.
- The energy engineer believes there is potential to reduce the unoccupied period AHU fan power usage by adjusting programming in the EMCS/building automation system (BAS).
- Figure E-3 shows the lighting to be turning off for the most part at nights and on weekends. There is an unoccupied lighting load of ~12 kW (~13% of the maximum). This is likely emergency egress lighting (required by code) but also may include some nonemergency lighting. There may be some potential to reduce this load.

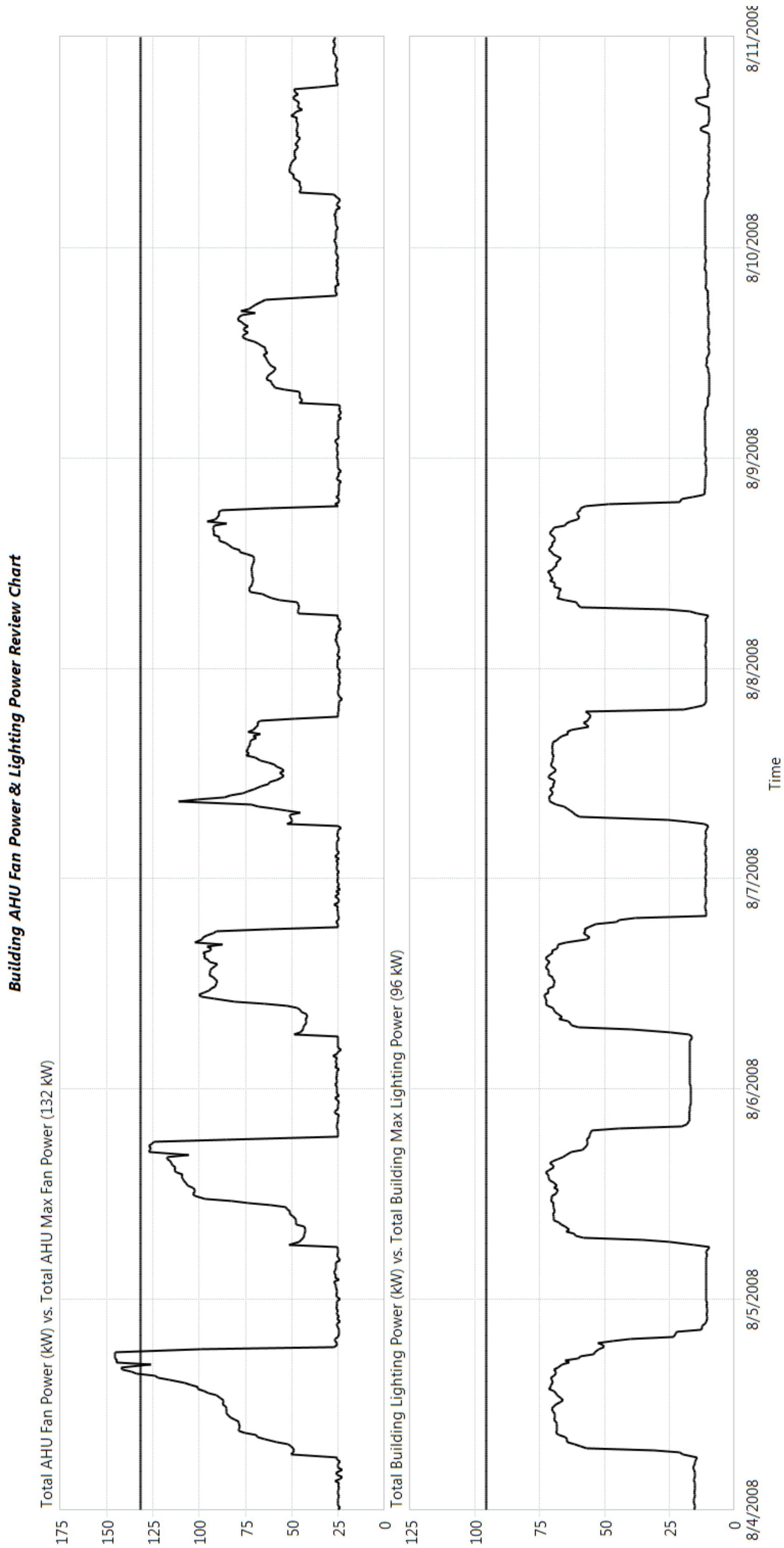


Figure E-3 Pre-Retrofit, 8/4/2008 through 8/11/2008 (Example 3)

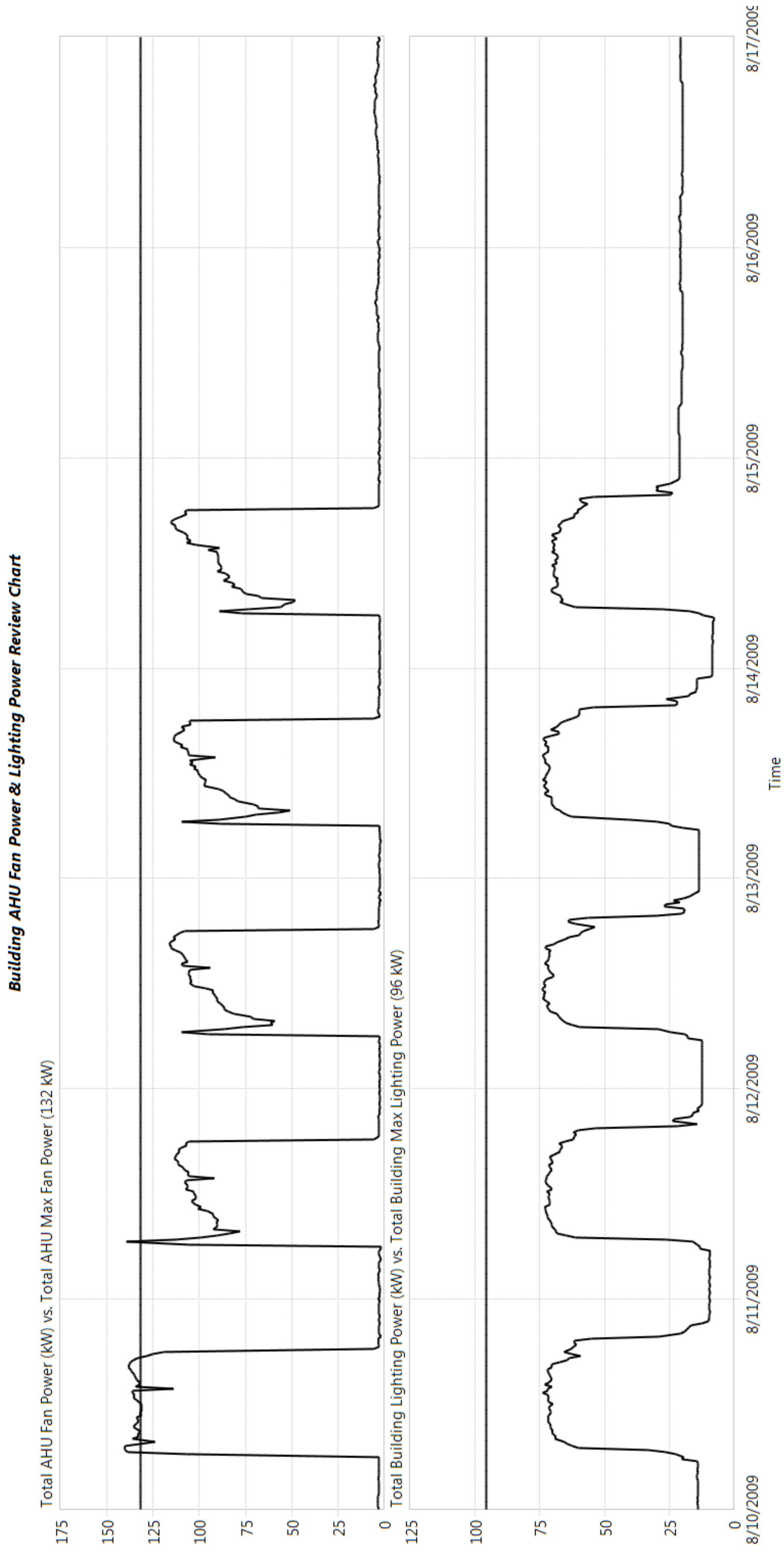


Figure E-4 Post-Retrofit, 8/10/2009 through 8/17/2009 (Example 3)

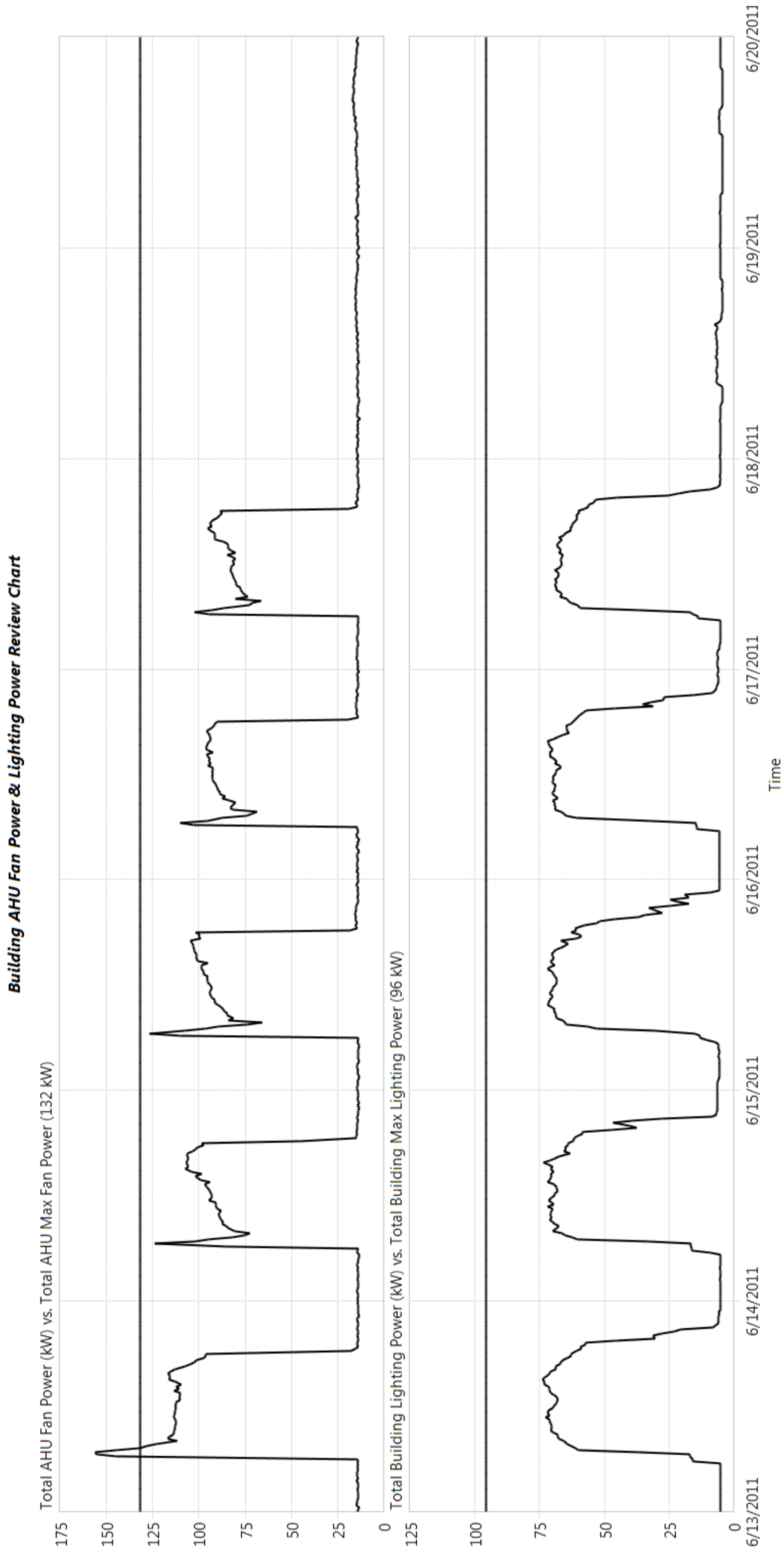


Figure E-5 Post-Retrofit Follow-Up, 6/13/2011 through 6/20/2011 (Example 3)

- Figure E-3 shows peak lighting power to be ~74 kW, which is ~77% of the maximum value of 96 kW. This is good because this tells us from a high-level perspective that the occupancy sensor and daylight harvesting lighting controls appear to be working.

RECOMMENDED CORRECTIVE ACTIONS

To reduce AHU fan power usage, the energy engineer recommends the following corrective actions:

- that the controls contractor modify the ERU schedule programming to shut the fans off completely on weekends and
- that the controls contractor modify the VAV terminal programming such that VAV cooling minimum airflows are reset to zero during unoccupied hours for all VAV terminals.

It is determined that the VAV terminal thermostat setpoints were resetting during unoccupied periods but the VAV cooling minimum airflows were not. Resetting the cooling minimum airflows to zero during unoccupied hours in effect allows the VAV dampers to go fully closed and stay closed unless cooling or heating is called for. This will not only reduce AHU fan power but also substantially reduce simultaneous heating and cooling, leading to additional energy savings. The AHUs will not be scheduled off but will instead be heavily reset and yet always available should the zones be used after hours.

Figure E-4 shows the impact of the proposed changes to the AHU system. We can see a significant difference in unoccupied *Total AHU Fan Power*, which approaches zero usage for all hours. In fact, the average for the week of 8/10/2009 through 8/17/2009 is 38.9 kW, which is ~22% less than the pre-retrofit comparison period (8/4/2008 through 8/11/2008) value of 49.69 kW. The usage during the occupied periods appears to be higher during the post-retrofit period, which is interesting. However, weather can influence this usage. We are more concerned with eliminating or heavily reducing the unoccupied period usage because we know that it should be very little since the building is unoccupied. Figure E-4 verifies that the implemented corrective action worked to reduce AHU and building energy usage. Figure E-4 also shows that the lighting has not yet been improved. In fact, the weekend unoccupied period usage appears to have increased to ~24 kW versus the previous value of ~12 kW. This is strange and recommended for continued investigation.

Figure E-5 shows a post-retrofit follow-up review of the building AHU and lighting systems. The good news is that the lighting systems modifications appear to be functioning well now since the usage is now much lower (i.e., 5 vs. 12 to 25 kW) during the unoccupied periods of weekday nights and weekends. The value of 5 kW is ~5% of the maximum, which is closer to what would expect if just the emergency egress lighting were on. Unfortunately, Figure E-4 also shows that unoccupied-period AHU fan power usage has increased from near 0 to ~12 kW for all hours.

This shows that energy investigation efforts are really never complete, since things are never static. The energy engineer recommends reviewing controls programming to see if possibly there were changes that increased unoccupied-period AHU fan power usage. The energy engineer further recommends updating the analysis on a periodic basis going forward (i.e., on a monthly basis, quarterly basis, etc.) to ensure that the building AHU and lighting systems continue to function in the most energy-efficient manner possible. If energy usage problems are discovered through evaluation of the higher-level *Total AHU Fan Power* and *Total Building Lighting Power* indicator variables, then the energy engineer can dig into the more detailed data that is available to find the specific problem areas so that the issues can be addressed.

EXAMPLE 4—REVIEW OF WSHP LOOP PUMP OPERATION FOR LARGE STATE GOVERNMENT OFFICE BUILDING

KEY POINT

This example shows how a simple change to a programmed EMCS setpoint makes a significant difference in pump energy usage.

OVERVIEW

A building of ~129,000 ft^2 has four floors and utilizes 54 water-source heat pumps (WSHPs) as the HVAC system to heat and cool the building. The WSHPs are all tied into a common loop that functions as both a heat source and a heat sink. A supplemental cooling tower keeps the loop maximum temperature from exceeding 85°F, while a supplemental boiler maintains the loop minimum temperature at 62°F. The loop distribution pumps are a pair of 20 hp pumps rated for ~700 hp, 70 ft w.g., and ~15 bhp. The loop is a variable-flow loop and the pumps are controlled by variable-speed drives to maintain the loop differential pressure at setpoint. The WSHPs have control valves on their condensers to limit loop flow as necessary. The differential pressure transmitter is located on the fourth floor while the pumps are located in the basement mechanical room. The controls sequence, per the original design documents, calls for both pumps to run as necessary to maintain the differential pressure at the setpoint of 10 psid. The sequence allows for only one pump running to meet the setpoint. In addition, the controls programming should also automatically determine and modify the lead-lag status of the pumps in a manner to approximately equalize run time between the two pumps. Finally, the controls sequence also calls for a pump minimum speed of 20 Hz or 33%.

The building's energy performance and systems are being reviewed as part of an overall building energy assessment study. The energy engineer includes an evaluation of the loop pumps as part of this energy assessment. The energy engineer uses the above-described sequence of operation as the self-reference benchmark for the operation of these pumps.

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The energy engineer obtains 15 minute trend data from the EMCS for the following three variables:

- Pump A speed → from VFD
- Pump B speed → from VFD
- Loop DP

The energy engineer then generates the two charts shown in Figures E-6 and E-7, which graphically illustrate the above variables over time. Figure E-6 illustrates a representative day of operation (April 12, 2011), while Figure E-7 shows the average value of these variables over the months of April 2011 through October 2011.

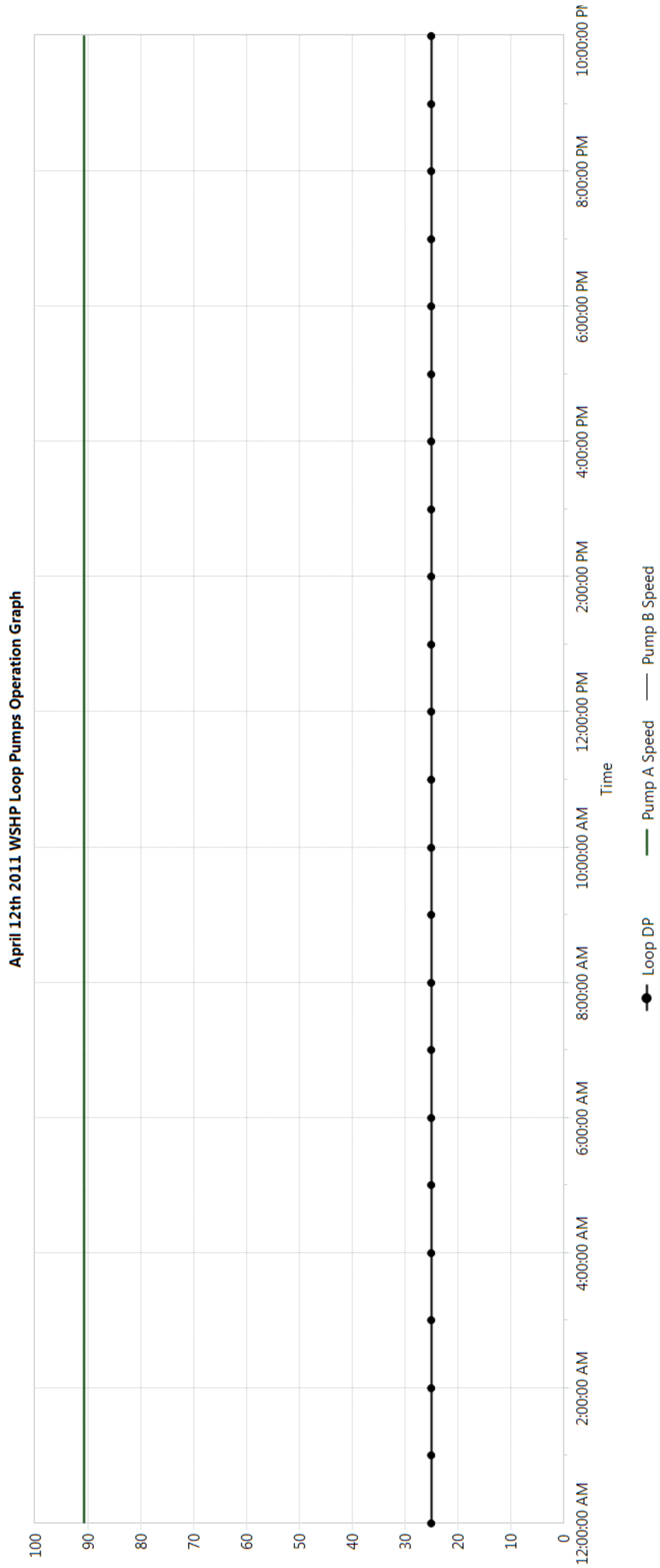


Figure E-6 Typical Pre-Retrofit Daily Pump Operation (Example 4)

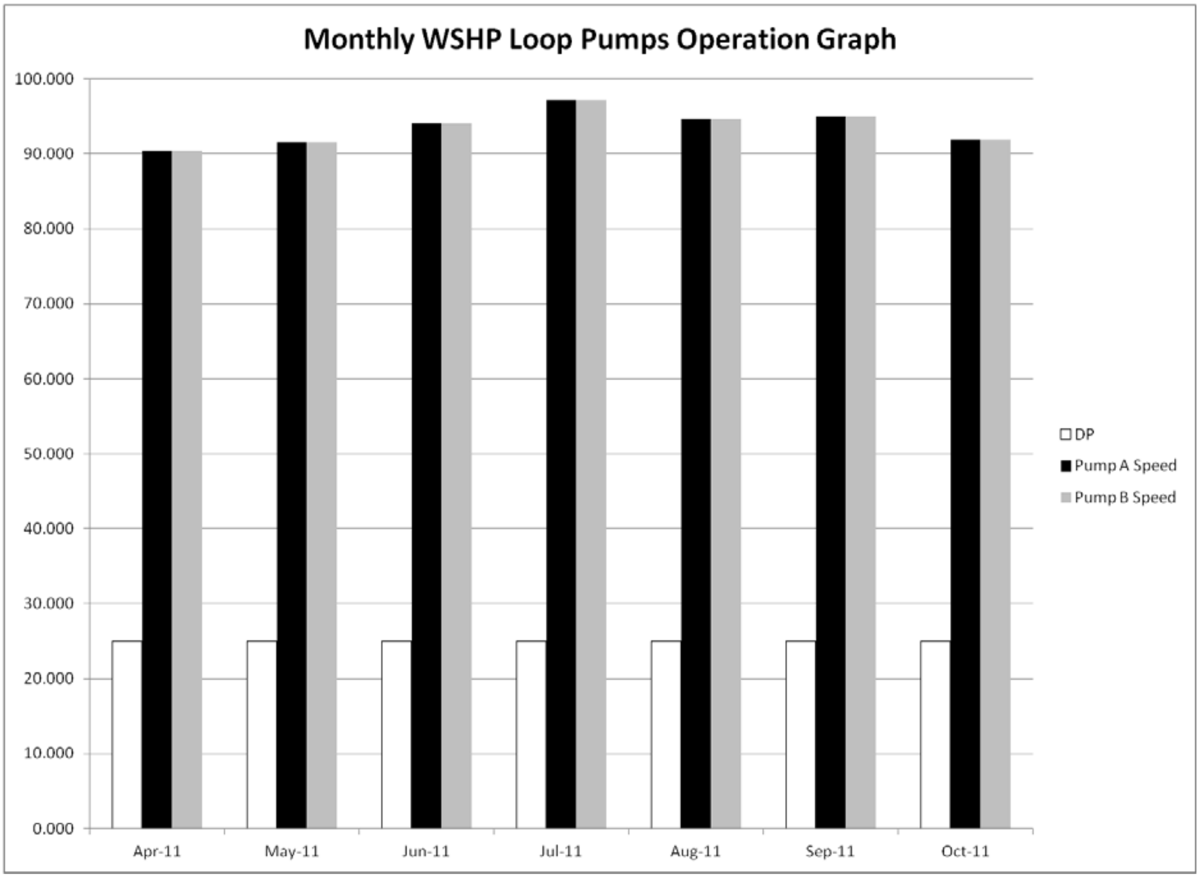


Figure E-7 Pre-Retrofit Monthly Pump Operation (Example 4)

OBSERVATIONS

The energy engineer notices from Figure E-6 that on a typical day both pumps run at 90% all the time and the loop differential pressure is 25 psid, not 10 psid.

In looking at the daily operations data, the energy engineer sees this is typical. Therefore, the energy engineer creates Figure E-7, which shows that the loop pumps were operating this way for just about all the time periods for which the energy engineer has pre-retrofit data. The pumps were always operating at speeds of at least 90% and the loop differential pressure was always 25 psid. The energy engineer concludes that these pumps have failed their self-reference benchmark for operating performance and are consuming significantly more energy than necessary.

Because of this, the energy engineer reviews this data with the facilities operations staff to try to better understand why these pumps are operating the way they are. The facilities operation staff does some additional investigation and determines that the loop differential pressure setpoint had mistakenly been entered as 65 psid (versus the correct value of 10 psid). This is because an EMCS graphic showed a loop setpoint and provided the ability to modify it on the graphic. However, the particular setpoint shown on the graphic was not identified as a loop temperature setpoint or a loop differential pressure setpoint. The setpoint had been interpreted as a loop temperature setpoint when it fact it was the loop differential pressure setpoint.

RECOMMENDED CORRECTIVE ACTIONS

The corrective actions were having the controls contractor update the EMCS graphic to clearly label the setpoint as the loop differential pressure setpoint and changing the setpoint to 10 psid. Post-retrofit performance is monitored as previously by trending the pump speed and loop DP variables.

Figure E-8 shows the post-retrofit performance after this change is implemented. This chart shows a significant improvement in performance because the pumps are now operating at speeds of between 55% and 60%, or 30% to 35% less than before. Before, the loop differential pressure setpoint was so high that the pumps simply did all they could subject to their maximum speed setting of 90%. After the differential pressure setpoint is changed to the correct value of 10 psid, the pumps can easily hit this setpoint while not having to run at their maximum speeds. Figure E-8 shows how a simple change in the loop DP setpoint results in significant pump energy savings.

Figure E-8 shows typical post-retrofit performance for a very mild weather period. In looking through the post-retrofit data, the energy engineer notices that the pump speeds never get below 55%, whereas the pumps should be allowed to go to 33% per the original sequence of operation. In addition, it appears that one pump could handle the job, but two are always running. Consequently, the energy engineer additionally recommends the controls contractor modify the pump sequence of operation and pump VFD settings to allow the pumps to run as low as 20 Hz or 33%, and to run only one pump if possible. This would lead to additional pump energy savings.

EXAMPLE 5—REVIEW OF OPERATION OF DOAS WITH ENERGY RECOVERY FOR LARGE STATE GOVERNMENT OFFICE BUILDING

KEY POINT

This example shows how simple changes to a programmed schedule and a programmed setpoint together result in significant energy savings for a rather complicated piece of equipment.

OVERVIEW

This example covers the same building as in Example 4. The building occupants are primarily present during the hours of 8:00 a.m. to 5:00 p.m. Monday through Friday. The WSHPs are provided outdoor air from a dedicated outdoor air system (DOAS), which is ducted to the WSHP returns. This DOAS is rated to provide ~10,500 cfm of outdoor air to the WSHPs. The DOAS is equipped with an exhaust-air total energy recovery wheel (i.e., an enthalpy wheel rotary heat exchanger), four 15 ton DX compressors and coils (60 tons total capacity), and a 30 kW electric reheat coil with a modulating SCR controller. The DOAS is also equipped with a sensible-only energy wheel located downstream of the DX coils for reheating purposes. The electric heating is located on the return air side such that if the supply air is desired to be reheated, heat is added to the return air so that it can transfer to the supply air via the sensible-only energy wheel. Figure E-9 schematically describes the components of this DOAS and their locations relative to each other.

The DOAS has its own controller but communicates information to the building EMCS via a BACnet® communications card (ASHRAE 2010e). The DOAS is equipped with its own temperature and relative humidity sensors and its own

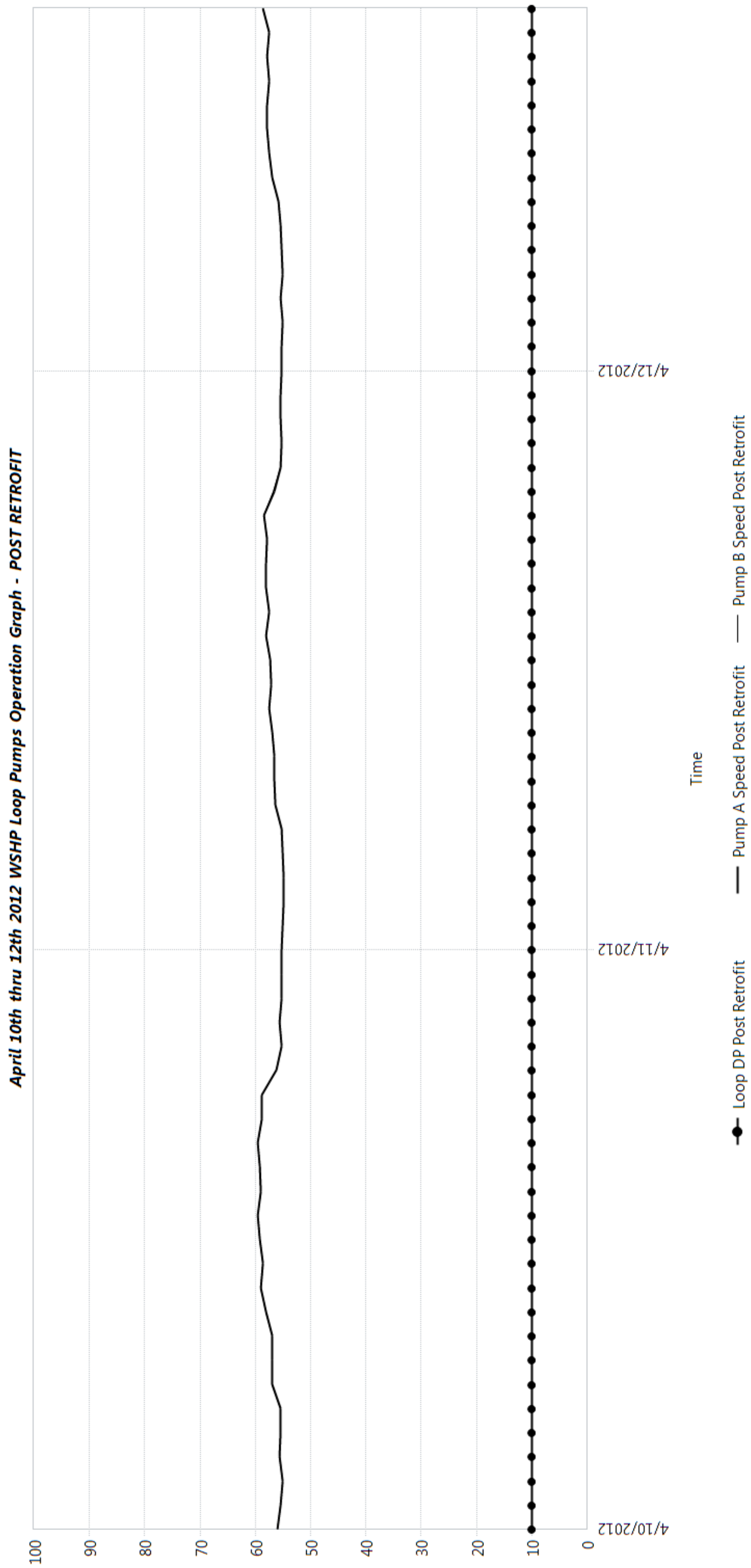


Figure E-8 Typical Post-Retrofit Daily Pump Operation (Example 4) program for calculating dew-point temperatures. The DOAS is also equipped with recirculation, outdoor air, and exhaust air dampers in order to provide for recirculation of building air during unoccupied periods (i.e., recirculation damper open, outdoor air damper closed, exhaust air damper closed).

The following is a summary of the intended sequence of operation for this unit:

- *Dehumidification mode:* The enthalpy wheel spins at full speed and the DX compressors are staged to attempt to deliver a 43.5°F dew-point temperature while also maintaining a supply air temperature of 65°F. The electric heating coil is used to boost the return air temperature to a high enough temperature to result in meeting the desired supply air temperature setpoint (65°F).
- *Cooling-only mode:* The DX compressors are staged to meet the supply air temperature setpoint. The sensible wheel and electric heater are disabled.
- *Heating mode:* The DX compressors are off (i.e., locked out when OAT < 40°F) and the sensible wheel is modulated to meet the supply air temperature setpoint of ~65°F. The enthalpy wheel operates also, but in a manner to prevent the exhaust-side leaving air from frosting.
- *Unoccupied mode:* The system is shut down during unoccupied periods (i.e., the fans are off and the dampers are closed) and only comes on if a space relative humidity sensor installed on the first floor rises to about 65% rh. When the ERU comes on during unoccupied periods, it is in recirculation mode, where building air is recirculated and the outdoor air and exhaust air dampers are closed.

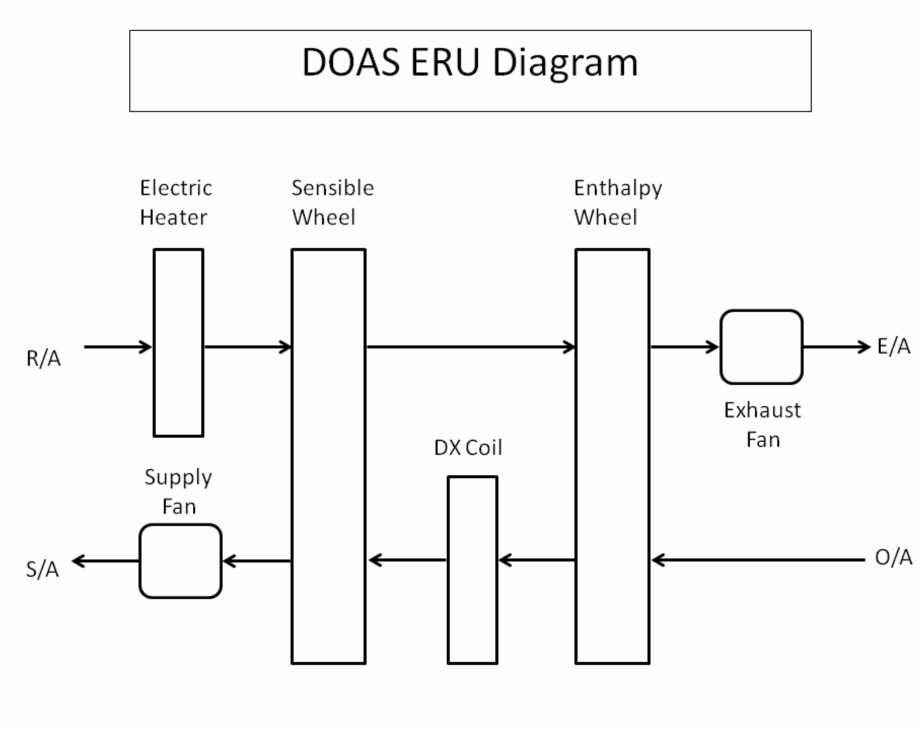


Figure E-9 need figure caption (Example 5)

The building's energy performance and systems are being reviewed as part of an overall building energy assessment study. The energy engineer includes an evaluation of the DOAS as part of this energy assessment. The energy engineer uses the above-described sequence of operation as the self-reference benchmark for the operation of the DOAS.

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The DOAS has multiple data points available for trending and analysis, including the following:

- DOAS operation status (0% or 100%)
- Operating status of each of the DX compressors (on/off)
- DOAS ERU supply air dew-point temperature (°F)
- DOAS ERU supply air temperature (°F)
- Electric heat status (on/off)
- Local outdoor air dew-point temperature, local to the DOAS (°F)
- First floor relative humidity

OBSERVATIONS

Based on the previous charts, the energy engineer has the following observations.

1. Figure E-10 shows typical weekly operation for a time period starting on 5/9/2011 (Monday) and ending at the beginning of 5/16/2011 (the following Monday) and reveals that the DOAS is running on both weekend days even though building occupants are not present.
2. Figure E-11 shows typical daily operation for the day of Tuesday, May 10, 2011, and reveals that the DOAS comes on a ~6:00 a.m. and turns off at 8:00 p.m., resulting in 14 hours of operation per day. However, the occupants are primarily present from 8:00 a.m. to 5:00 p.m, or 9 hours per day. Therefore, the DOAS is operating perhaps a bit too early and a bit too late, and its hours of operation could perhaps be trimmed.
3. Figure E-12 shows that the DOAS can only meet the dew-point setpoint of 43.5°F when the ambient dew-point temperature reaches the low 40s. The chart also shows, however, that the DOAS supply air dew-point temperature is lower than the ambient dew-point temperature.
4. Figure E-12 shows that all four of the DX compressors are running nearly all the time at 100% during occupied hours, trying to help the DOAS reach a setpoint that it can seldom reach.
5. During this time period, the first floor relative humidity varies between 35% and 45%.
6. Figure E-12 also shows the heating status is mostly ON during occupied hours. The SCR controller output signal is unavailable for trending. However, reheating is occurring due to the DOAS ERU supply air temperature, which is higher than the supply air temperature expected leaving the DX coils. Certainly, the sensible wheel is providing most of this reheat via the return air. A power meter to quantify the actual electric heating.
7. This is a very mild time of the year with regards to dew point; the building is located in a mixed humid climate zone in the south, and the location is such that the dew-point temperature is generally above 70°F during the months of June through September. Consequently, with the

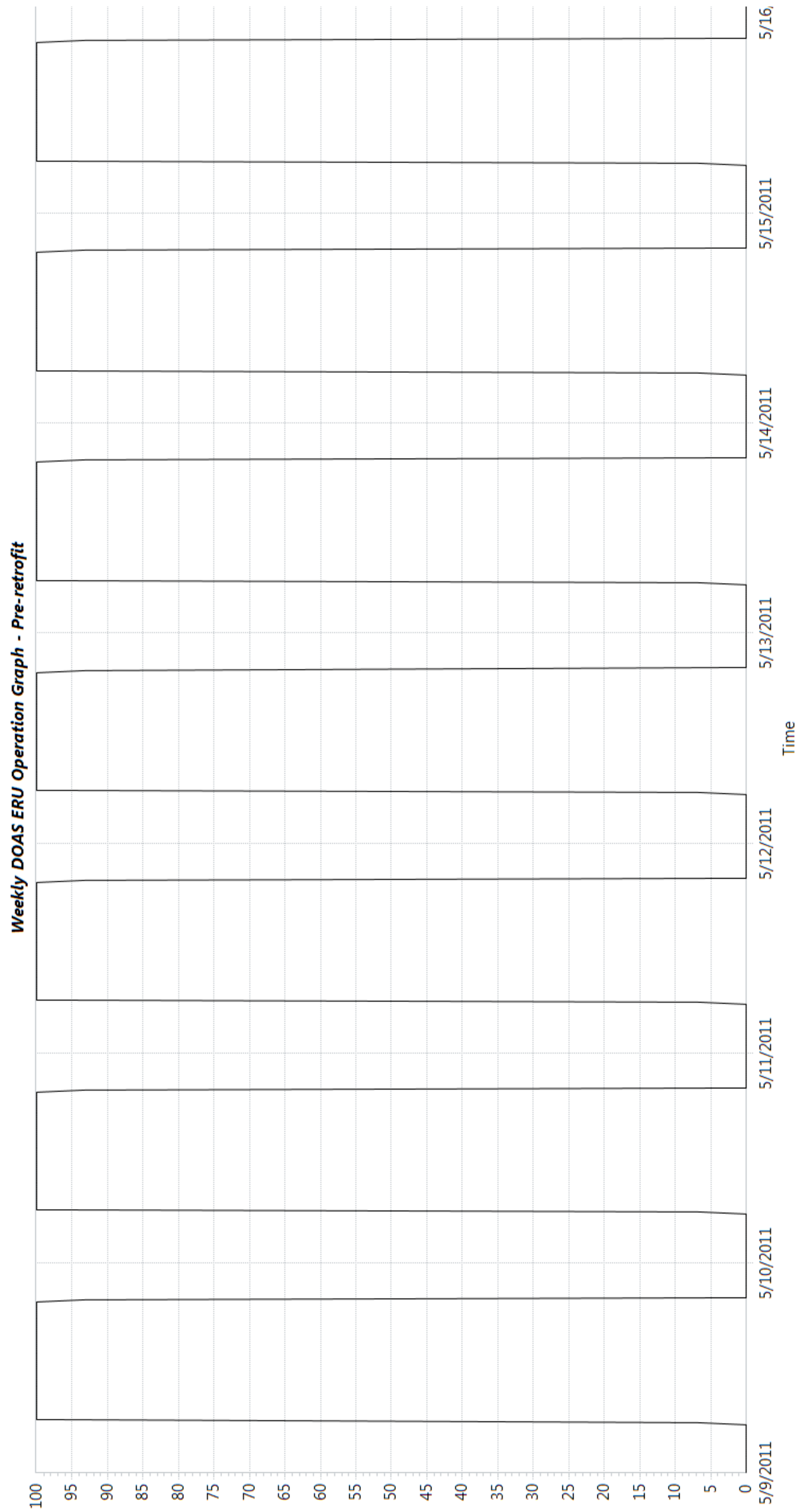


Figure E-10 Typical DOAS Scheduled Weekly Operation, Pre-Retrofit (Example 5)

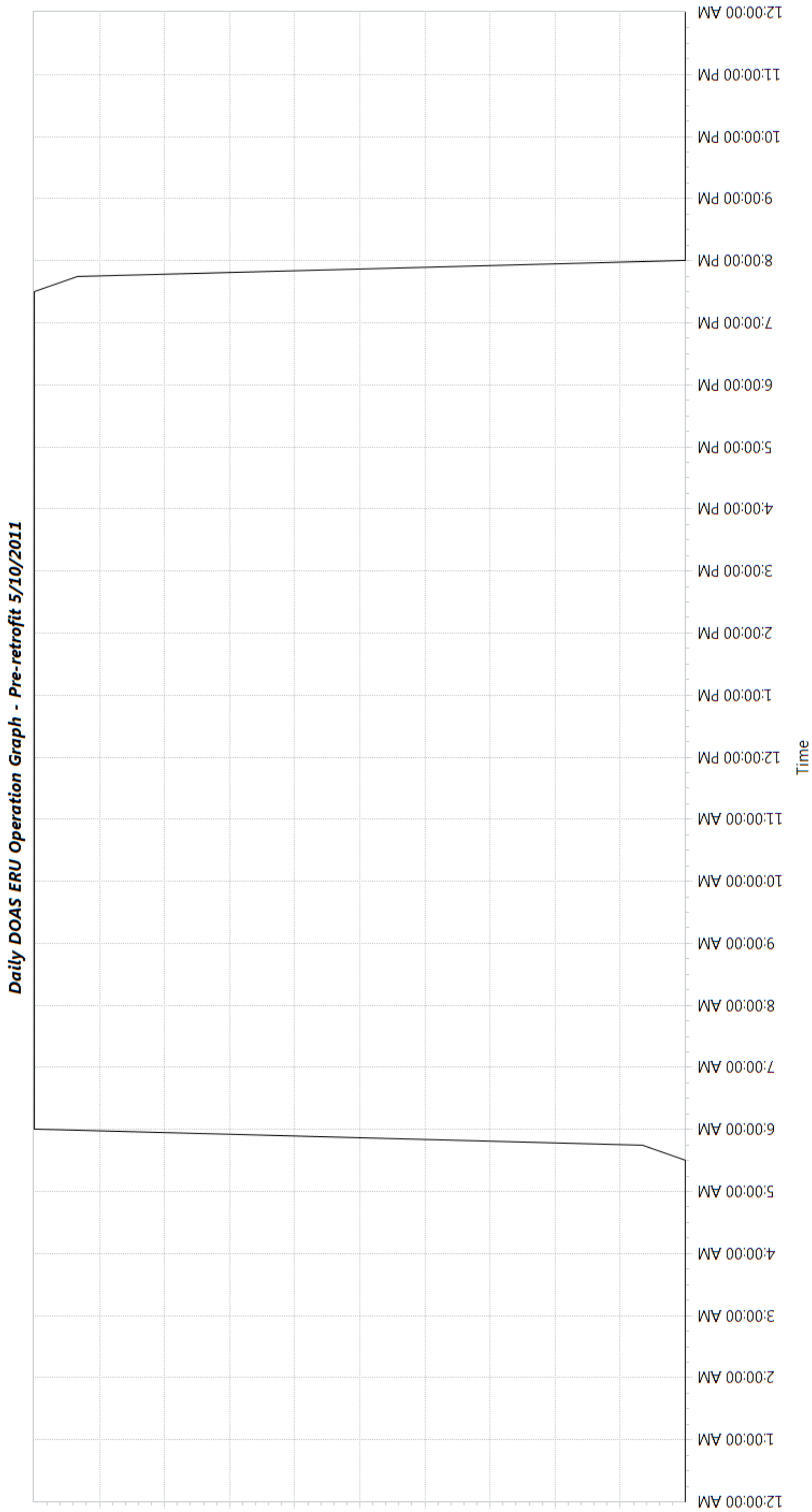


Figure E-11 DOAS Typical Scheduled Daily Operation, Pre-Retrofit (Example 5)

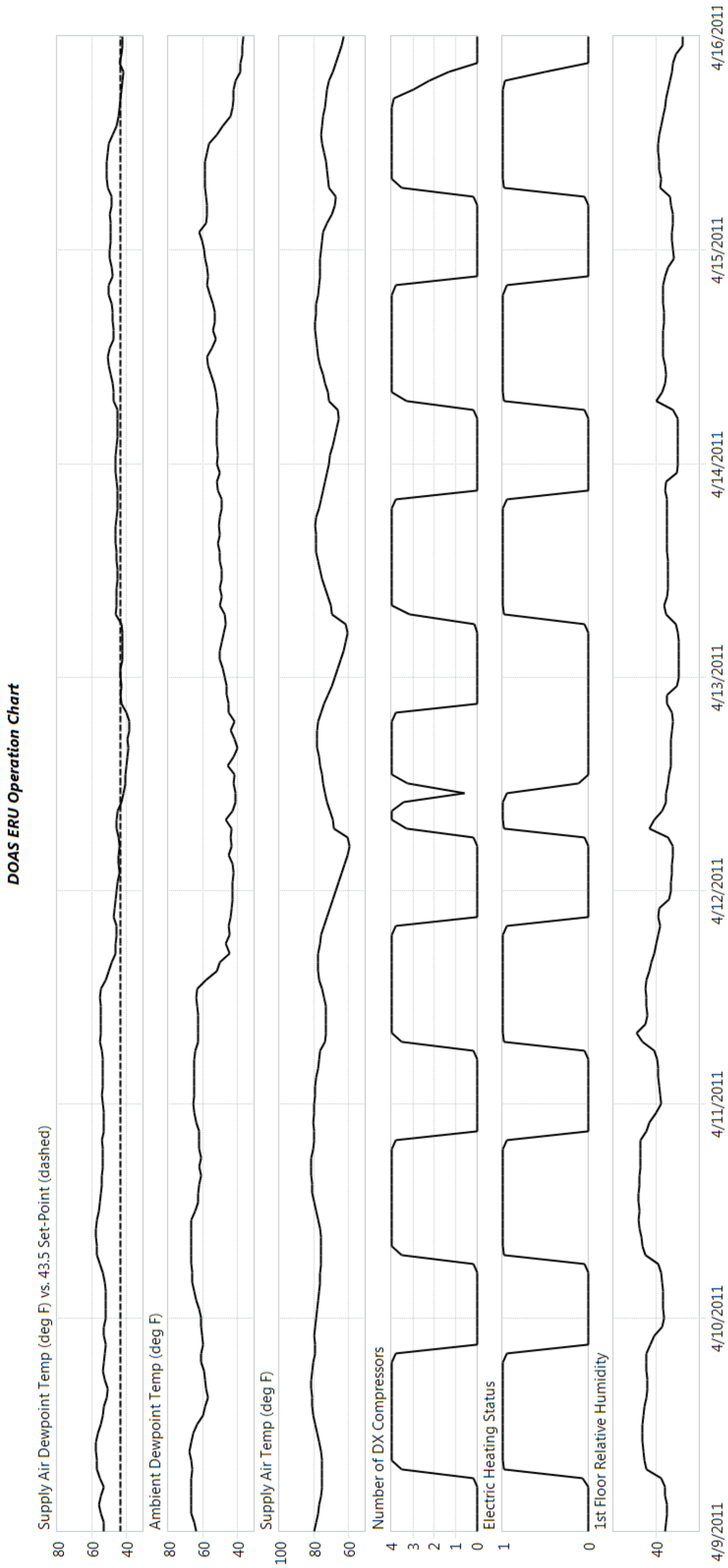


Figure E-12 DOAS Operation Chart, Pre-Retrofit (Example 5) current setpoint of 43.5°F, all four DX compressors will run for a significant portion of the year, trying to meet a setpoint that cannot be met.

8. It is unclear why a dew-point setpoint of 43.5°F would ever be necessary. First, the system in the building is WSHPs, which have their own inherent ability to dehumidify and therefore control space relative humidity. The building does not have a system such as chilled beams, which have no ability to dehumidify and thus require ventilation air to have additional moisture-absorbing potential for absorbing the space latent gains.
9. In addition, the DOAS does not include a technology that allows for a dew-point setpoint of 43.5°F to be reached during a significant portion of time in actual operating conditions. Perhaps active desiccant technology could achieve such a feat, but standard DX compressors cannot.
10. Based on this review, the DOAS should be programmed for a more reasonable dew-point temperature setpoint.

RECOMMENDED CORRECTIVE ACTIONS

The first recommended corrective action is to modify the DOAS programmed schedule of operation in the EMCS to operate only Monday through Friday and during the hours of 7:30 a.m. to 5:30 p.m. This would better reflect operation of the DOAS when the occupants are present. The overall hours of operation per week would be reduced from 98 hours per week (14 hours/day at 7 days/week) to 50 hours per week (10 hours/day at 5 days/week), or a 49% reduction in run time. This recommendation reinforces the idea that there is no better way to save energy than by turning a piece of equipment off. If the operation is deemed unnecessary, the unit can and should be turned off to save energy. The energy engineer believes the DOAS unit can be run at reduced hours while still providing acceptable indoor air quality for the building occupants. This simple corrective action will result in significant energy savings for the owner.

The second corrective action involves how to make the DOAS more efficient and use less energy when it is running during occupied hours. To accomplish this, the energy engineer simply recommends using a dew-point temperature setpoint of 55°F. The energy engineer believes that this is a feasible setpoint that can be achieved by the DOAS while not running the DX compressors at 100% all the time.

Figures E-13 through E-15 illustrate the post-retrofit performance after these changes are made. Figure E-13 shows typical post-retrofit weekly operation during a period from 4/2/2011 (Monday) through 4/9/2011 (the following Monday) and verifies the DOAS is now off on weekends. Figure E-14 shows typical post-retrofit daily operation for Monday, April 2, 2012, and verifies that operation is now reduced to 7:30 a.m. to 5:30 p.m., or to 10 hours per day. Figure E-15 shows the DOAS operation for a post-retrofit time period (10/8/2011 through 10/15/2011) where the ambient dew-point temperature is very similar to the pre-retrofit conditions (4/9/2011 through 4/16/2011). This chart shows the DX compressor operation practically vanishes with the new setpoint, resulting in significant energy savings. In addition, the first floor relative humidity only increases slightly and is still well within the range of acceptable relative humidity. There is still some reheating going on; we just are not sure how much. The DOAS ERU post-retrofit supply air temperature is lower, indicating that less reheating is going on. However, an additional recommendation can be made to simply disable the elec-

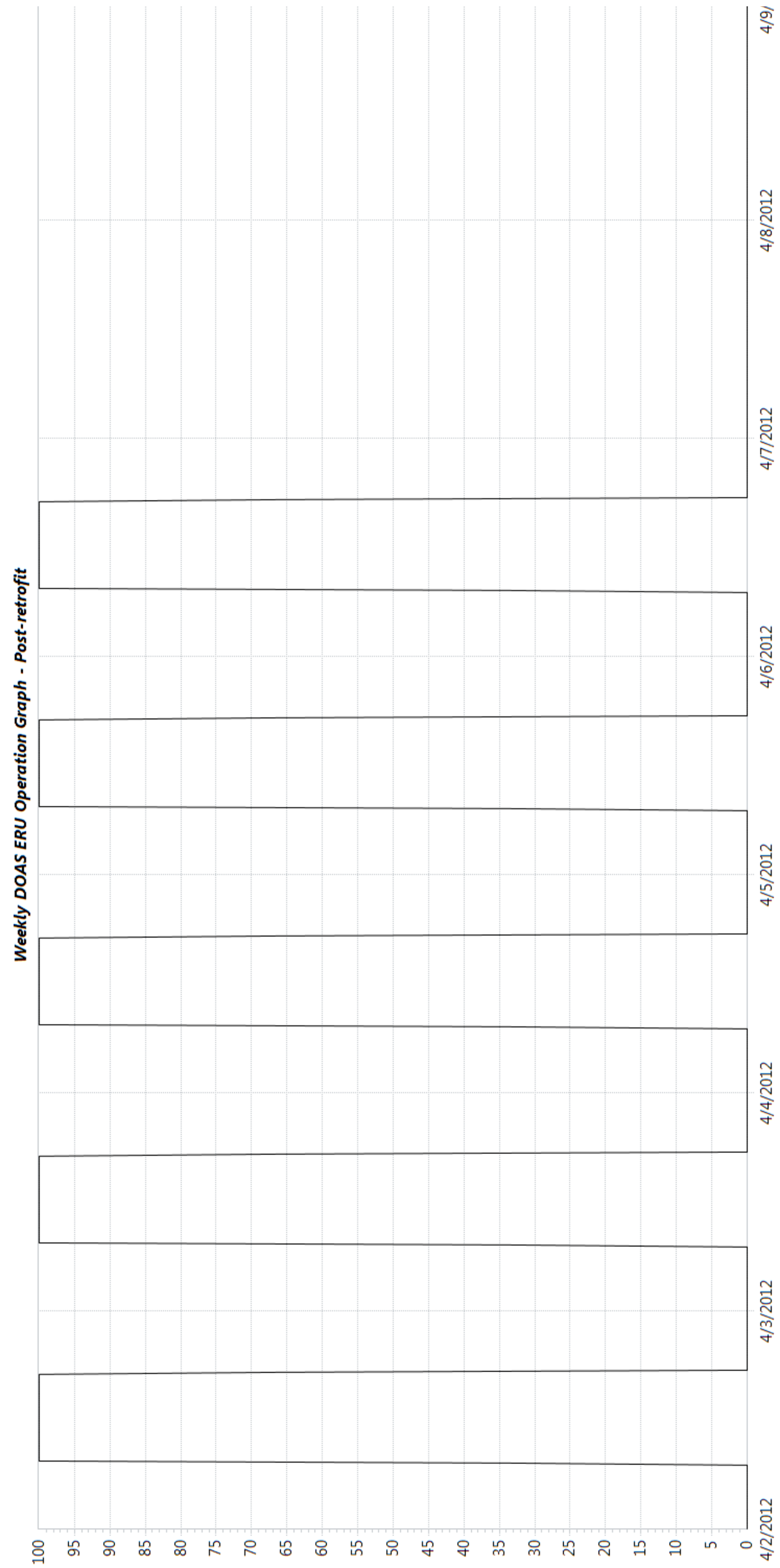


Figure E-13 Typical DOAS Scheduled Weekly Operation, Post-Retrofit (Example 5)

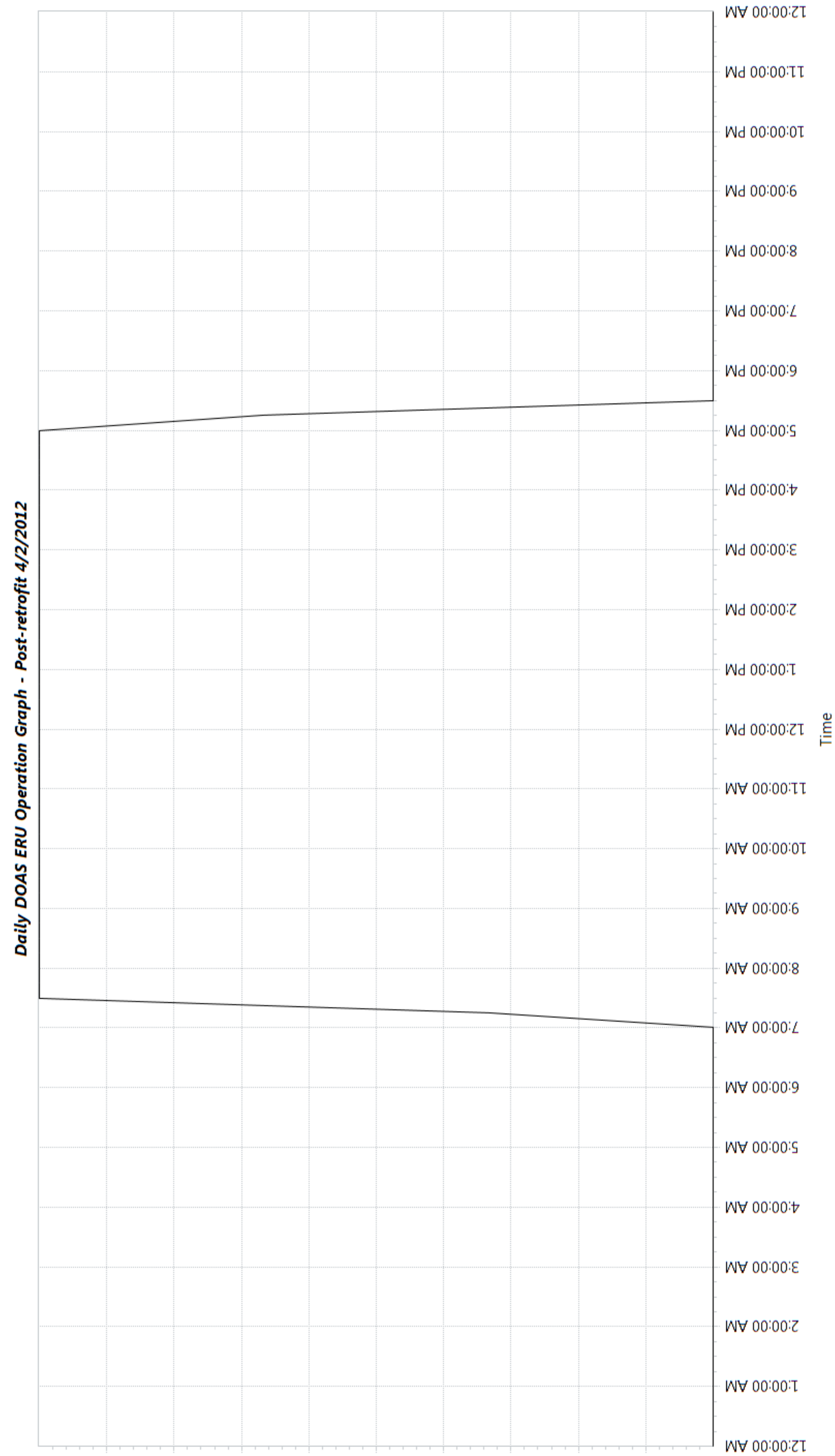


Figure E-14 Typical DOAS Scheduled Daily Operation, Post-Retrofit (Example 5)

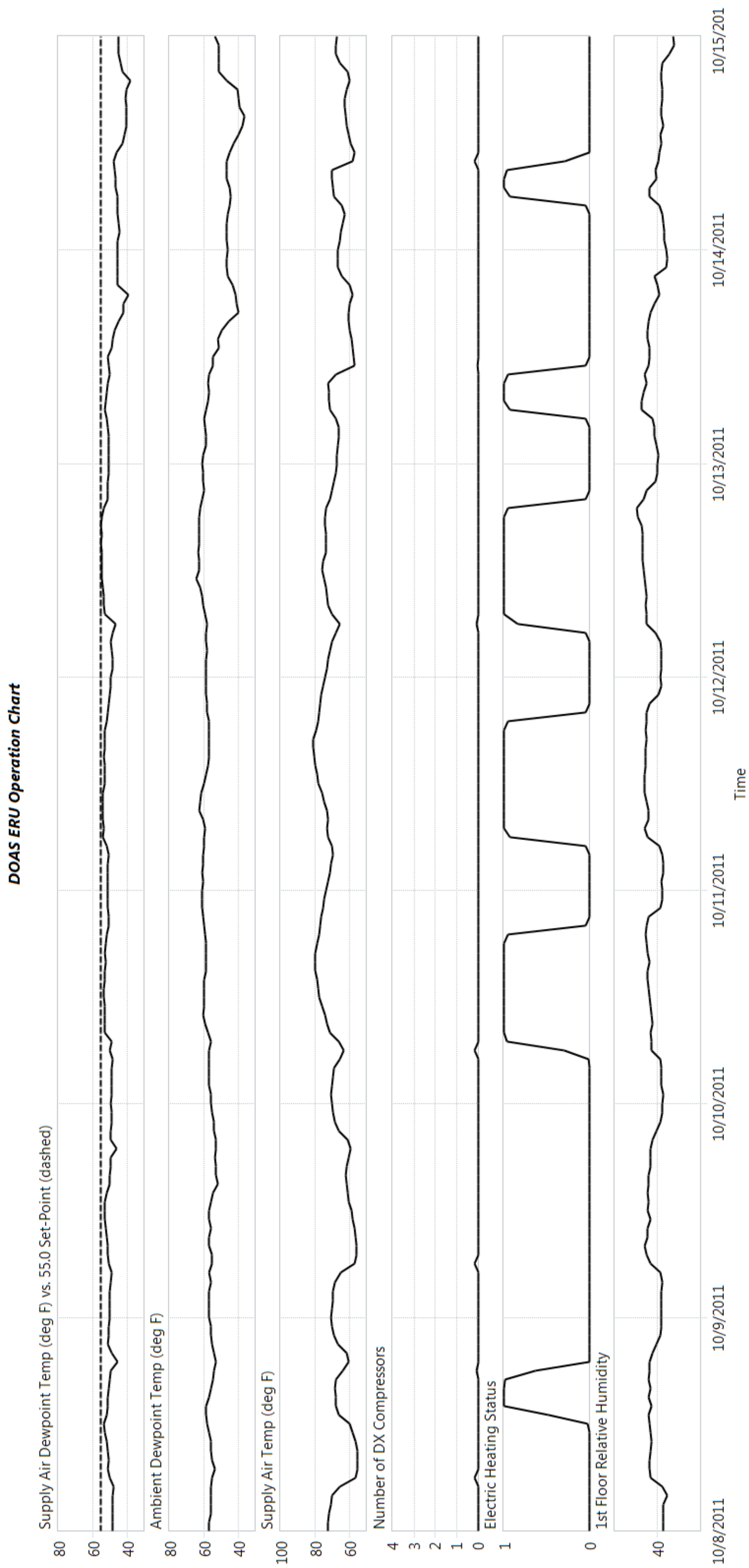


Figure E-15 DOAS Operation Chart, Post-Retrofit (Example 5) tric heating and sensible-only wheel during warm weather periods (i.e., when the OAT > 70°F). This would save additional energy because we have already cooled the outdoor air. Providing this cold air to the WSHPs would reduce the cooling work they have to do.

Overall, significant energy savings result from simply changing the programmed schedule and one key setpoint.

EXAMPLE 6—REVIEW OF ENERGY RETROFIT PROJECT FOR A SMALL HIGHER EDUCATION BUILDING

KEY POINT

This example shows that the use of occupancy sensors to automatically control VAV terminals can result in substantial energy savings when conventional scheduling is difficult to program in the EMCS. This is a simple and inexpensive addition to existing equipment.

OVERVIEW

A small higher education classroom building is ~24,000 ft^2 and is conditioned by AHUs that are provided cooling via an 80 ton air-cooled chiller. The AHUs provide conditioned air to 33 VAV terminals located through the building that are equipped with electric heating elements. This is an all-electric building. Like many facilities, the VAV terminals have programmed minimum airflow settings in order to ensure the adequate distribution of ventilation air to the occupied spaces. Ideally, the VAV terminals and AHUs would be scheduled to reset their operation when the building zones are unoccupied. However, the specific issue with this building is that it is very difficult to schedule. The building hours of occupancy vary significantly due to the needs of the students but also various special events that are held in the building.

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The building has an EMCS that is capable of trending several variables on the AHUs, chiller, VAV terminals, etc. The energy engineer decides to collect detailed trend data on the VAV terminals to confirm their operation. The trended VAV terminal data includes the following variables:

- Space temperature (°F)
- Space temperature setpoint (°F)
- Discharge temperature (°F)
- Actual airflow (cfm)
- Desired airflow (cfm)
- Electric heating status (on/off)
- Electric heating amount (kW) → created by energy engineer in the UT software (PEC 2012) based on electric heating status and the rated kilowatt capacity of the VAV terminals

To get a good idea of how the existing systems are operating, the energy engineer creates charts of the above variables for each of the VAV terminals using the UT. Examples of these charts are shown in Figure E-16 (VAV terminal 1-1) and Figure E-17 (VAV terminal 1-33).

OBSERVATIONS

The first observation is that the energy engineer confirms what he initially suspected: that because the building is difficult to schedule, there is no scheduling.

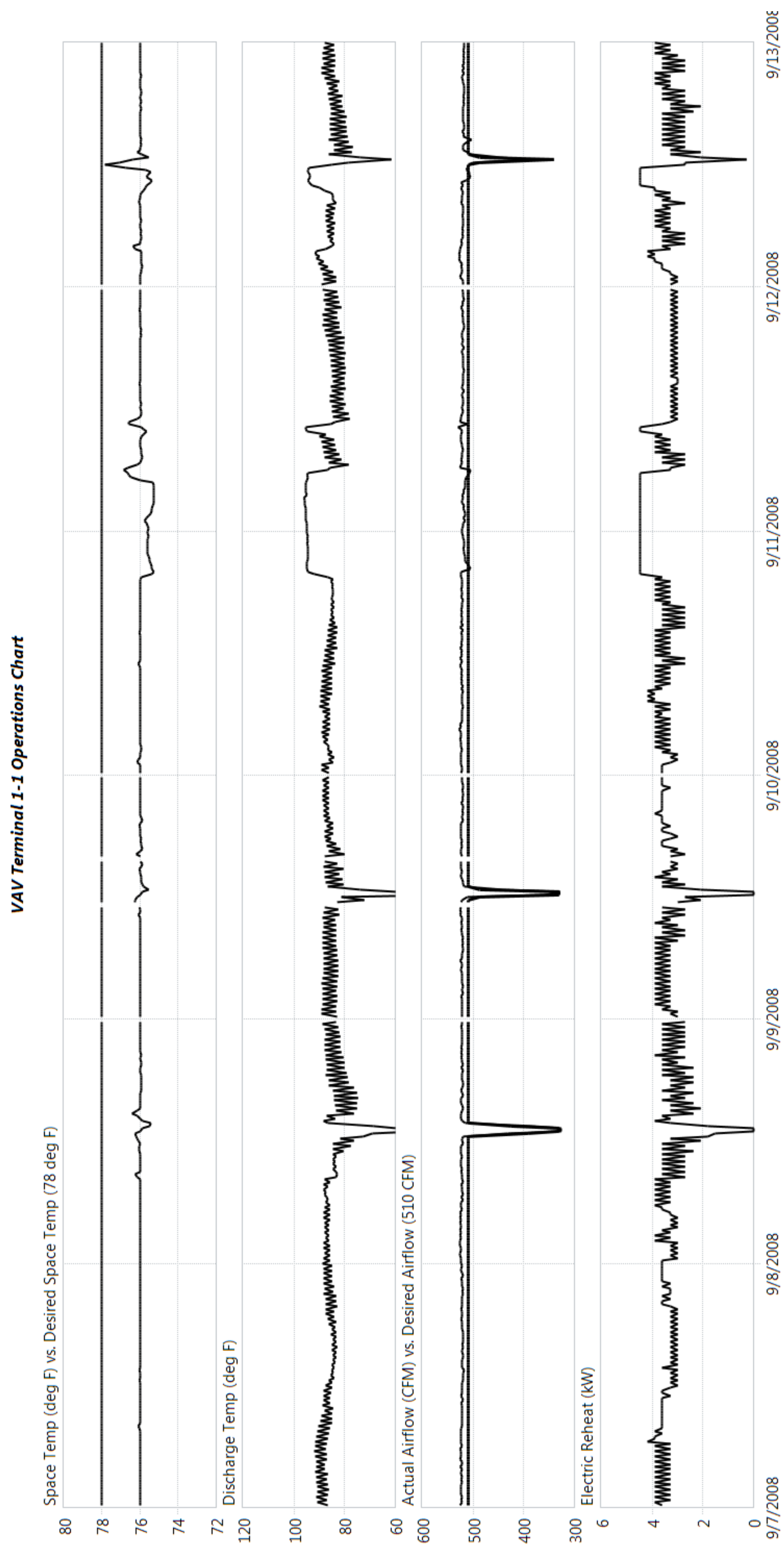


Figure E-16 VAV Terminal 1-1 Typical Pre-Retrofit Operation (Example 6)

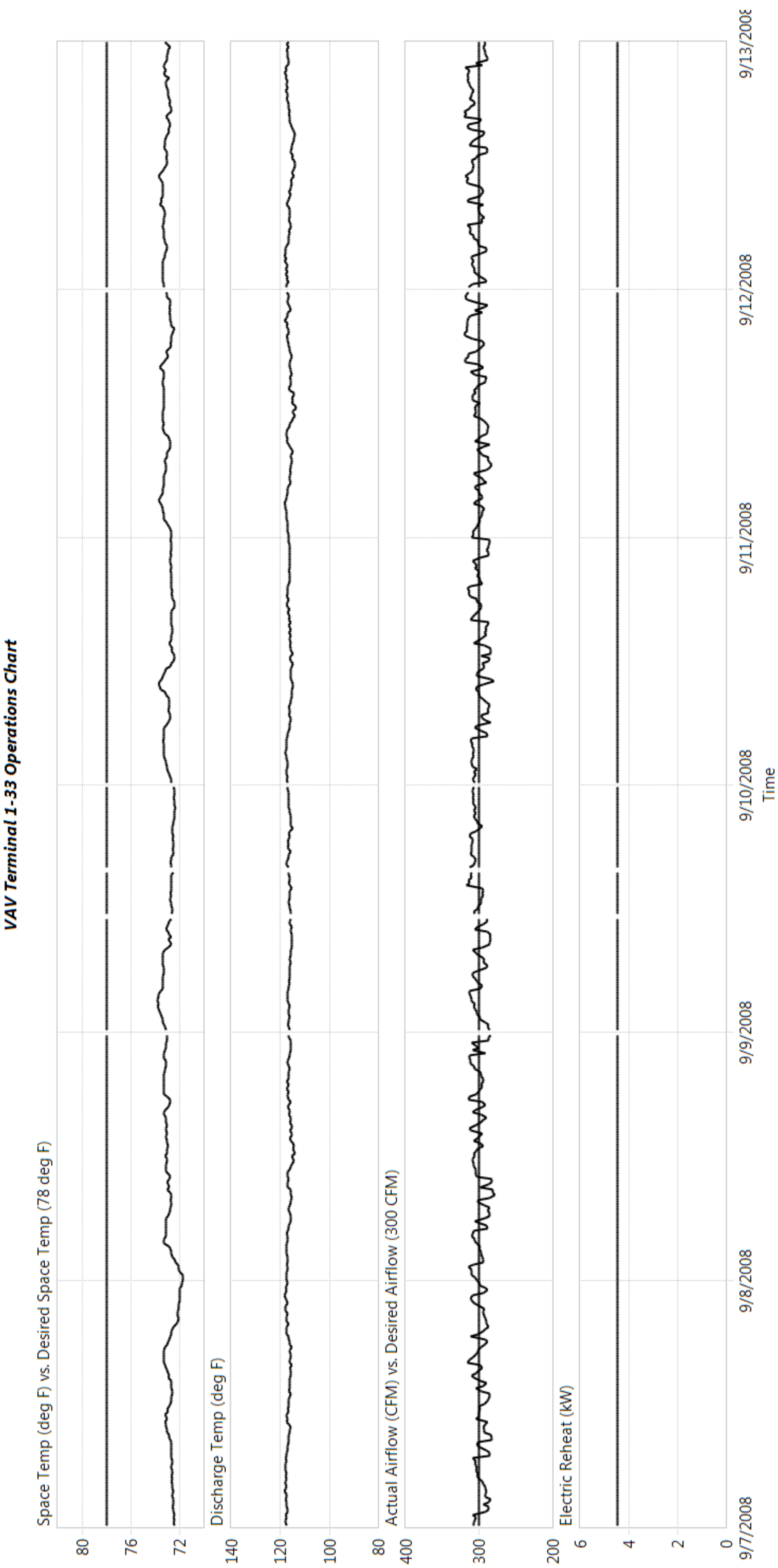


Figure E-17 VAV Terminal 1-33 Typical Pre-Retrofit Operation (Example 6)

This is the main point to be had from this example. It is not realistic to assume that facilities operation staff has the time on their hands to constantly adjust programmed schedules to meet the ever-changing needs of the building occupants. For facilities with highly variable occupancies, it is more likely that no programmed schedules exist.

Figure E-16, showing the chart for VAV terminal 1-1, is representative of the VAV terminals throughout the building, meaning that neither thermostat setpoints nor airflow setpoints are reset at all. The operation of VAV terminal 1-1 is typical of VAV terminals that do not have their minimum airflows reset. In this case, the minimum airflow setpoint is ~500 cfm, which is enough to overcool the space such that reheating is necessary. In addition, the electric reheat is made worse because the occupant has set the thermostat to 78°F, perhaps thinking that this is energy efficient. Actually, because the airflow is fixed, more reheat is necessary in order to try to maintain the space temperature at the setpoint of 78°F. Figure E-16 shows that the VAV terminal cannot meet this setpoint. Consequently, the electric reheat runs most of the time and the best the VAV terminal can bring the space to is ~76°F. Surely, this situation can be improved.

Figure E-17,showing the chart for VAV terminal 1-33, is not representative of the rest of the VAV terminals but instead has its own issues. This VAV terminal serves a large open area that another VAV terminal also serves. There are two issues. First, the thermostat that controls this VAV terminal is not located in the area served by the VAV terminal. Second, the control of the two VAV terminals that serve the same large open area is not coordinated such that they each receive the same control command. The end result is that VAV terminal 1-33 is always reheating and sending hot air into the space while the other VAV terminal (1-26, not shown) is always sending cold air into the space. This is a tremendous waste of energy, which certainly can be improved.

RECOMMENDED CORRECTIVE ACTIONS

The main corrective action is to install occupancy sensors to turn off lighting when occupants are not present but also to connect the relay output of the occupancy sensors to the VAV terminal controllers. This allows the VAV terminals to reset setpoints when the building occupants are not present. Connecting to the lighting allows for quick visual observations to tell if the occupancy sensors are actually working.

The VAV terminal programming is specifically modified to reset the cooling minimum airflow setpoint to 0 cfm when no occupants are detected in the zones via the occupancy sensors. However, the thermostat temperature setpoints are not reset unless all occupancy sensors for all VAV terminals are registering unoccupied (i.e., building occupancy variable). This allows for the spaces to have appropriate temperatures maintained while the building is occupied. The space thermostat setpoints are basically reset only if the entire building is unoccupied. Otherwise, the energy engineer is worried that there would be complaints (e.g., if occupants have to wait for space temperatures to come to occupied levels). However, the majority of the excessive energy usage is due to the programmed minimum airflow settings. Therefore, resetting the minimum airflow settings to zero when spaces are unoccupied will result in the majority of the energy savings.

In addition to resetting minimum airflows based on occupancy status, the specific problems associated with VAV terminals 1-33 and 1-26 are easily solved by relocating the thermostats to be within the area served by the terminals and modifying the controls programming to coordinate the control of the terminals such that they get the exact same control signals for heating and cooling, which will eliminate these VAV terminals fighting each other all the time.

Overall, this example illustrates two common situations with VAV terminal type systems: no scheduling and uncoordinated control for VAV terminals serving the same large open areas. VAV terminals are worrisome from an energy perspective because they can cause the building to use significant amounts of energy through excessive simultaneous heating and cooling when they are operated in constant-volume applications. Nobody would even know about this unless they were specifically looking for it. The spaces still feel quite comfortable so the occupants would not know there are problems. VAV systems are unique because no other HVAC system type has the potential to waste as much energy as VAV systems. Thus, specific and focused attention on VAV systems is warranted and highly recommended. The attention needs to be focused on the VAV minimum airflows and whether they can be reduced during both occupied and unoccupied hours. There are many commercial buildings with VAV systems. If the industry can focus on this one area alone, significant energy savings are possible.

To wrap up this example Figure E-18 is presented to show both the pre-retrofit and post-retrofit energy performance of the building. An energy retrofit project for this building primarily consisted of the modifications discussed here. The post-retrofit period was August 2010 through July 2011. The pre-retrofit data shown is an average of the two years prior to the post-retrofit period.

Figure E-18 verifies that the implemented corrective actions worked to significantly reduce overall building energy consumption. Previously, an energy audit of the building revealed that the 50% of the baseline building energy usage was due to the electric heating alone. Detailed review of the post-retrofit data verified that the VAV terminals' minimum airflow setpoints were being reset to zero when the zones were unoccupied. This led to a substantial reduction of electric reheating, which helped the building to achieve overall energy savings of approximately 50%, which is reflected in Figure E-18.

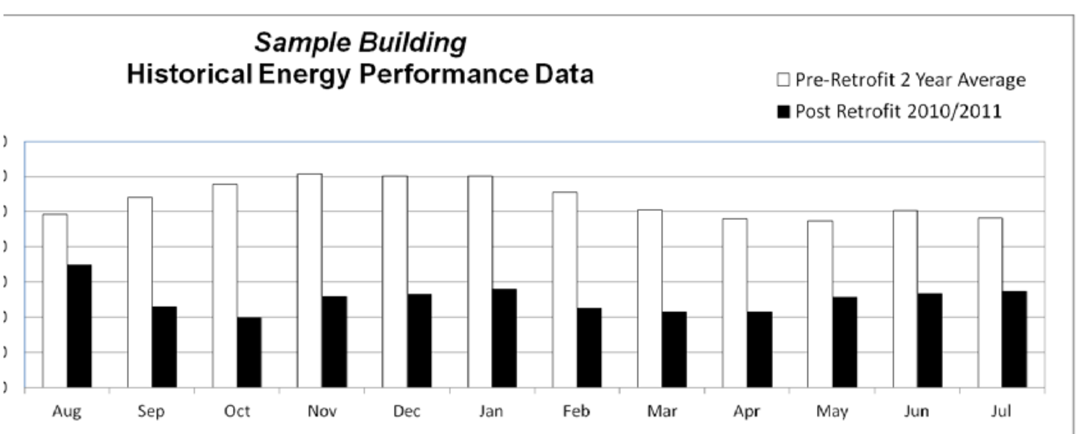


Figure E-18 Total Building Energy Performance Review, Pre-Retrofit vs. Post-Retrofit (Example 6)

EXAMPLE 7—REVIEW OF 75 TON PRTU ECONOMIZER OPERATION FOR SMALL COMMERCIAL OFFICE BUILDING

KEY POINT

A low-cost replacement of a faulty equipment controls sensor can result in energy savings.

OVERVIEW

A small commercial office building, approximately 24,500 ft^2 in size, is served by a single 75 ton packaged rooftop unit (PRTU). The PRTU is equipped with six DX compressors and an outdoor air damper that is capable of controlling to a minimum amount of outdoor air or opening up to full economizer operation (i.e., 100% outdoor air). The return air temperature and humidity are measured and the return air enthalpy is calculated. Similarly, the outdoor air temperature and humidity are measured and the outdoor air enthalpy is calculated. The PRTU controller is configured to engage the economizer cycle when the outdoor air enthalpy is less than the return air enthalpy. This is known as *differential enthalpy economizer control*. If the outdoor air enthalpy is less than the return air enthalpy, the outdoor air damper will be modulated to maintain the mixed-air temperature at setpoint. The maximum amount of outdoor air during economizer operation is 8,000 cfm. The minimum amount of outdoor air during non-economizer operation is 1,900 cfm.

This choice of economizer control works quite well, except when the relative humidity sensors do not work, which results in incorrect calculation of enthalpy values and therefore incorrect control commands issued by the controller.

MEASUREMENT AND ANALYSIS PLAN DESCRIPTION

The EMCS for this building has the capability to monitor and trend multiple variables. The energy engineer decides to review the operation of the economizer controls by obtaining and reviewing trend data for the following variables:

- Outdoor airflow (cfm)
- Outdoor airflow setpoint (cfm)
- Outdoor air temperature (°F), relative humidity (%), and enthalpy (Btu/lb)
- Return air temperature (°F), relative humidity (%), and enthalpy (Btu/lb)
- DX compressor status for all six compressors (on/off) → summed by the energy engineer in the UT software (PEC 2012) by creating a virtual variable
- PRTU supply air temperature (°F)
- PRTU supply air temperature setpoint (°F)

These variables are graphically shown in Figures E-19 through E-21 for the representative day of April 2 through April 3, 2012, 10:00 a.m.

OBSERVATIONS

The following observations are made by the energy engineer based on Figures E-19 through E-21.

1. First, Figure E-19 shows the PRTU is off during unoccupied hours. That is good.
2. Figure E-19 also shows the economizer to be engaging during occupied hours when the outdoor air enthalpy (blue) is less than the return air

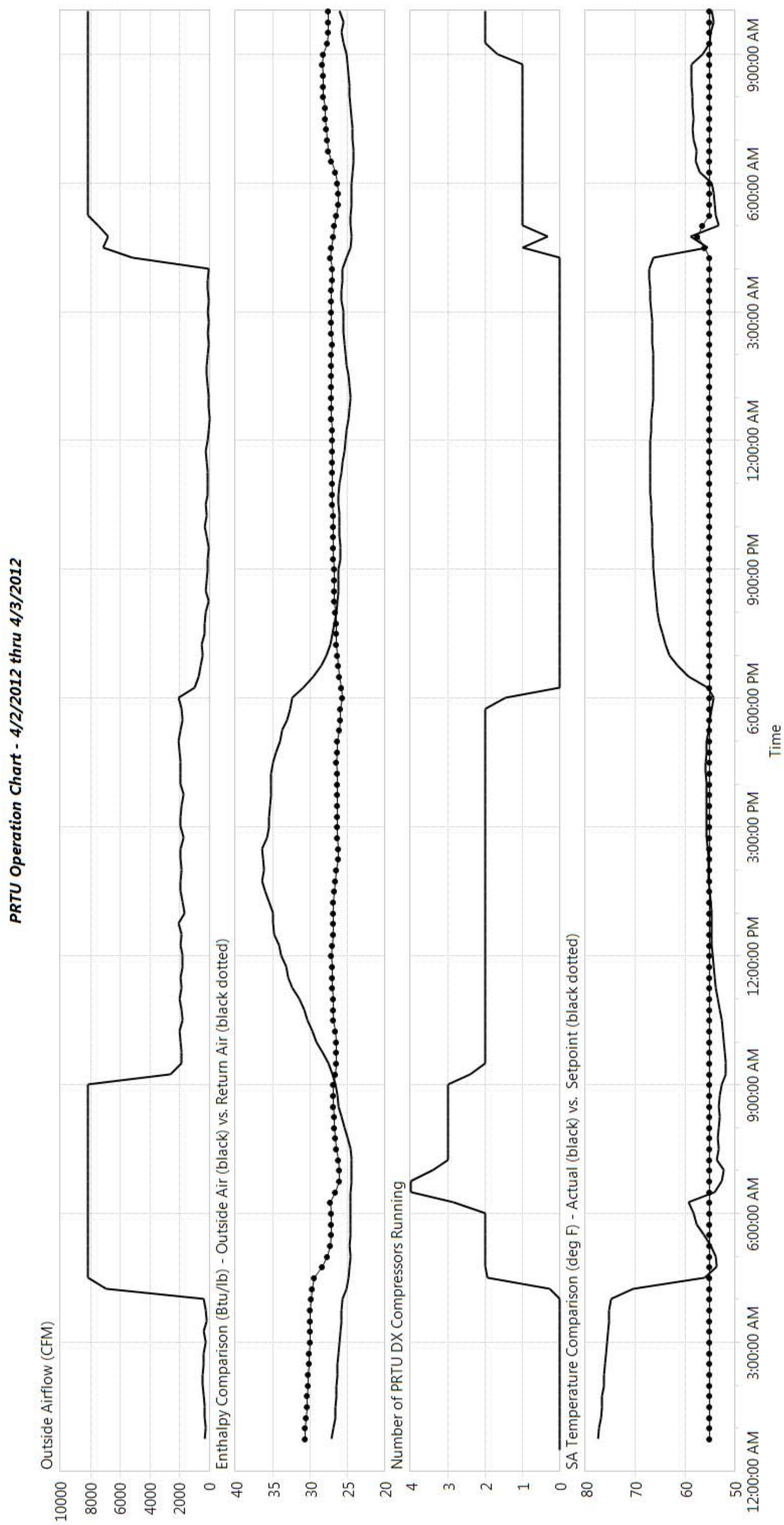


Figure E-19 PRTU Operation Chart, 4/2/2012 through 4/3/2012 (Example 7)

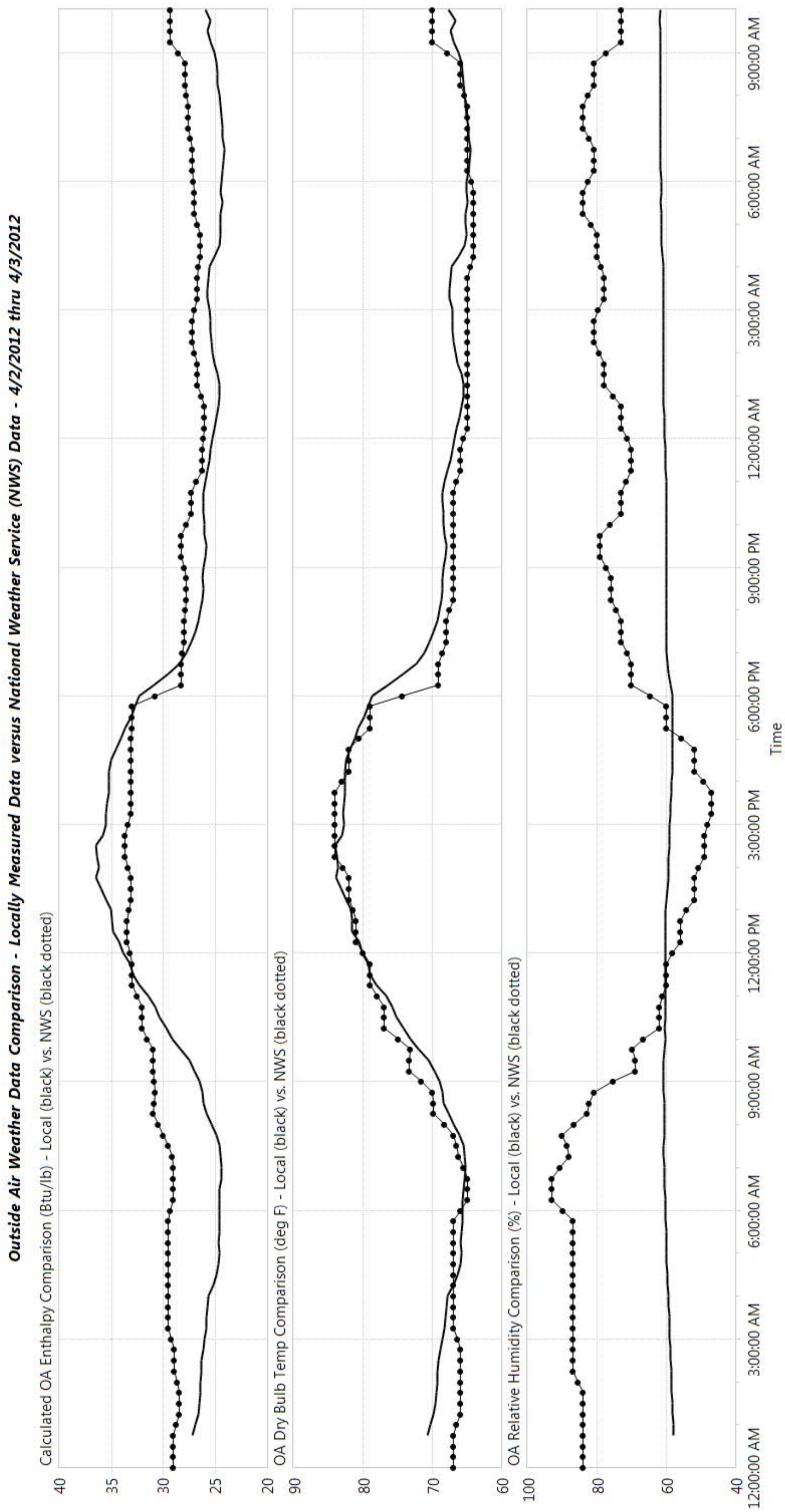


Figure E-20 Outdoor Air Weather Data Comparison, 4/2/2012 through 4/3/2012 (Example 7)

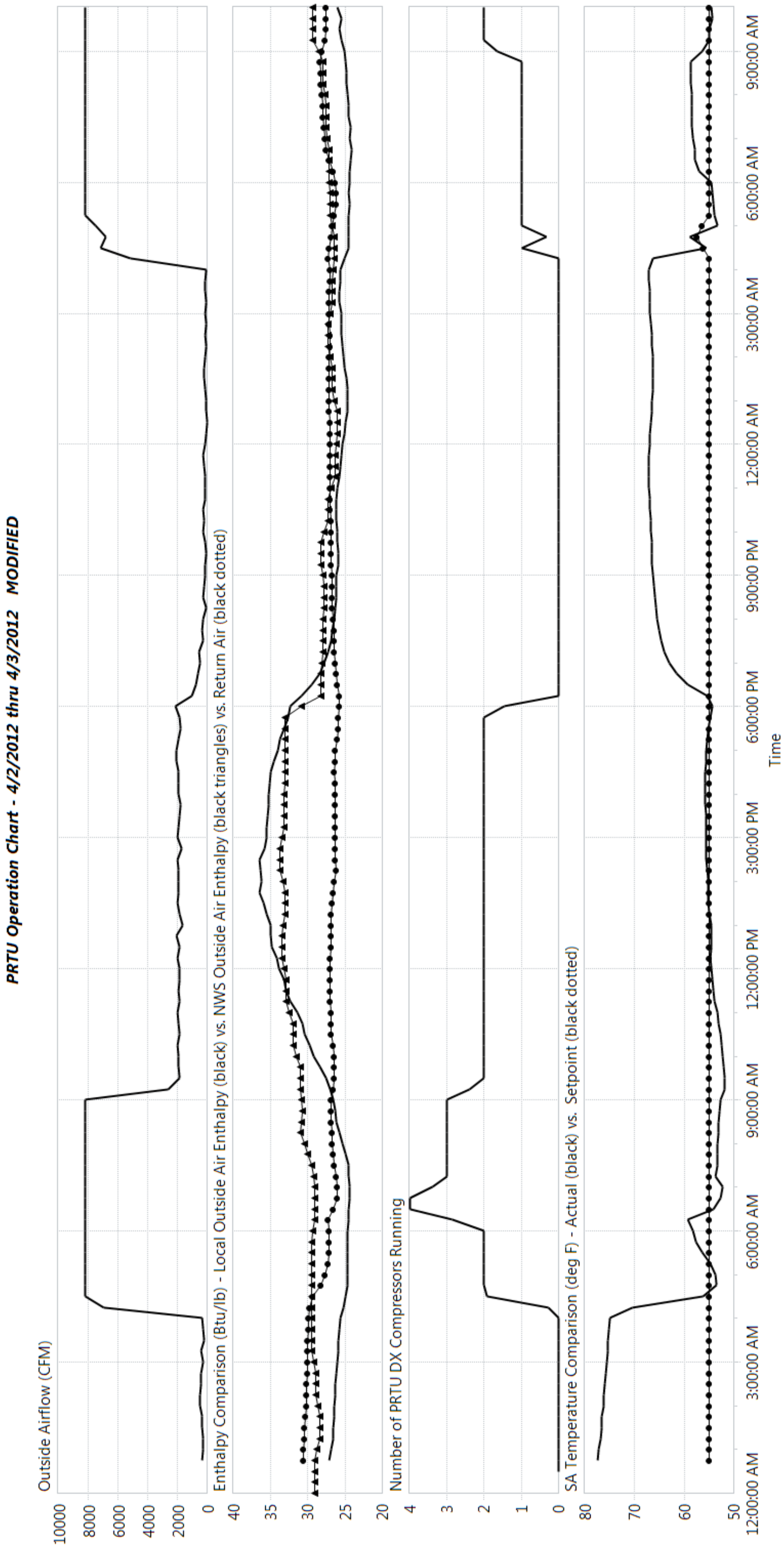


Figure E-21 Modified PRTU Operation Chart, 4/2/2012 through 4/3/2012 (Example 7) enthalpy (red). However, when the outdoor air enthalpy exceeds the return air enthalpy, the economizer cycle is disengaged and the outdoor air amount drops to the minimum occupied value of ~1900 cfm.

3. This is great news! Let's call it a day and say the economizer appears to be working great and move on.
4. Well, except, let's take another look from another angle, which is a highly recommended best practice for energy engineering practitioners. (Never look at system operation from one point of view.)
5. Figure E-19 also shows the compressor usage actually increases when the economizer cycle is engaged, which is a strong clue that something is not right. Granted, in this particular setup it is possible that the compressors run some even during economizer operation in order to maintain the overall PRTU supply air temperature at setpoint. However, the usage of the compressors should not increase when the economizer is engaged and decrease when the economizer is disengaged.
6. Figure E-19 strongly suggests that the outdoor air enthalpy value is not correct. If it were correct, the number of operating DX compressors would decrease when the economizer is kicked on, not increase.
7. Figure E-20 shows a comparison of local outdoor air data to National Weather Service (NWS) data from a local NWS airport weather station located ~4 miles from the building. The local and NWS outdoor air enthalpy values are calculated using the UT software psychrometrics channel (PEC 2012) and the local and NWS outdoor air temperature and relative humidity data. There is a big difference in outdoor air enthalpy in these two data sets.
8. Further examination of Figure E-20 shows the outdoor air temperatures actually compare pretty well, so it is clear they are not the problem.
9. However, Figure E-20 shows a big difference between the locally measured relative humidity values in the EMCS and the NWS data. More specifically, the locally measured relative humidity sensor appears to have failed because it is stuck at nearly 60% all the time.
10. The locally measured relative humidity value of 60% results in generation of outdoor air enthalpy values that are (in this case) lower than the relative humidity really is. This leads the controller to incorrectly activate the economizer, which then leads to more DX compressor operation that would have otherwise occurred had the economizer controls been disabled.
11. Figure E-21 is similar to Figure E-19 but shows (in the second chart) a line of outdoor air enthalpy per NWS data (the black line with triangles) versus a line of outdoor air enthalpy per local data (the black solid line) versus a line of return air enthalpy (the black dotted line), which clearly shows the economizer to be engaged when it should instead be off because the outdoor air enthalpy is really greater than the return air enthalpy, not less than the return air enthalpy.
12. The bottom line is that a single faulty outdoor air relative humidity sensor is causing the PRTU to waste energy instead of save energy, which is disappointing.

RECOMMENDED CORRECTIVE ACTIONS

There are a few choices for correcting the problem discovered with the economizer control.

1. Replace the existing outdoor air relative humidity sensor with a high-quality sensor.
2. Instead of measuring the outdoor air temperature and humidity, have the EMCS automatically retrieve this information from the NWS Web server for the airport weather station that is located only 4 miles away, as the NWS measurement instrumentation appears to be more accurate and is maintained. Automatic polling and retrieval of this data for use in EMCS controls programs is possible and has been done. In the event of loss of communication with the NWS Web server, the PRTU can simply revert to dry-bulb-only economizer control using the locally measured ambient dry-bulb temperature, which compares pretty well with the NWS data.
3. Implement the first corrective action but periodically compare the performance of the local sensor to the NWS data, using a chart similar to that shown in Figure E-21. Replace the sensor when it is determined to be necessary, as in the current situation.
4. Modify the EMCS programming to eliminate the use of differential enthalpy economizer control and instead control the economizer based on outdoor air temperature only. More specifically, engage the economizer cycle when the outdoor air temperature is less than 55°F. This may not result in as much theoretical savings as the theoretical enthalpy economizer control option provides. However, this is preferable in the real world versus control utilizing incorrect enthalpy values, which actually results in the economizer controls wasting energy versus providing energy savings.

All of the above options are low-cost options that will result in energy savings for the PRTU with regards to current operation. Consequently, the energy engineer recommends at least one of the options be implemented right away.

Appendix F
Water Verification Workbooks

This appendix includes forms that are found in the *Basic Level Water Verification Workbook* and the *Diagnostic Level Water Verification Workbook*. The forms and charts are Microsoft® Excel® spreadsheets that are fully accessible and editable. The forms include the General Input Form, Utility Bill Data Input Form, Prior Year or Baseline Data Input Form, Water Use Charts, Water Cost Charts. While the General Input form is fairly self explanatory, an instructions tab provides information on how to fill out the data input forms. The charts are automatically populated based on the data entered into the worksheets. Examples of the data input form and the charts are shown in this appendix.

Water definitions and supporting charts and tables needed to assist the user in filling out the forms are also provided in this appendix.

GENERAL INPUT FORM

Example worksheet comes from the Excel file: Level 1 Water Verification Worksheet 12-31-10.xls Use the worksheet on the General Input FormTab.

BASIC EVALUATION DATA INPUT FORM EXAMPLE

Example worksheet comes from the Excel file: Level 1 Water Verification Worksheet 12-31-10 R1.xls Use the worksheet on the Utility Bill Tab. Show Page 1 ONLY

BASIC EVALUATION CHART EXAMPLES

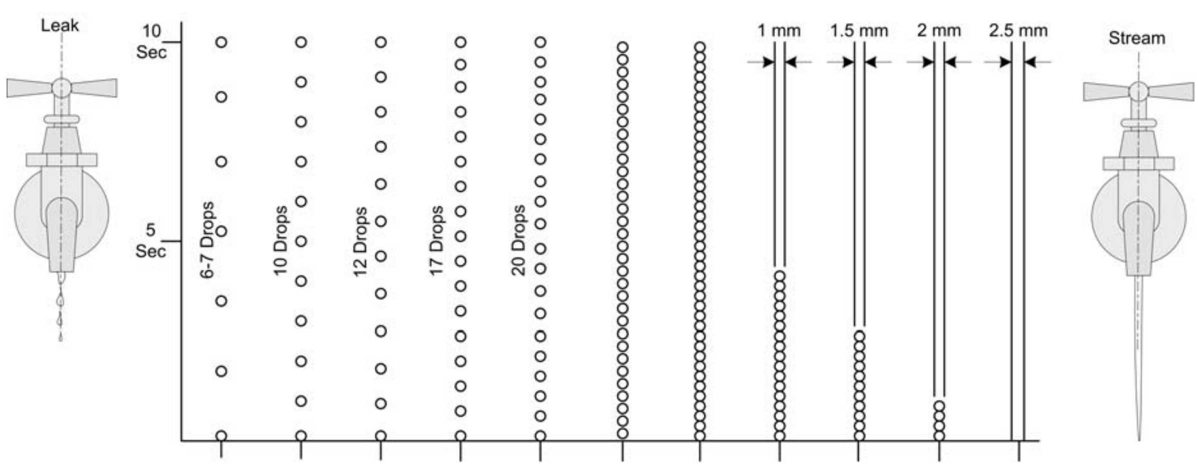
Example graphs come from the Excel file: Level 1 Water Verification Worksheet 12-31-10.xls Use Water Use Charts tab and Water Cost Charts tab.

WATER DEFINITIONS

Bleed	=	CT blowdown
CE	=	controller efficiency
CT	=	cooling tower
Cycles	=	cycles of concentration of solids in the condenser water
Drift	=	CT mist ejected from the tower
ET_L	=	evaporation rate
ET_O	=	evapotranspiration rate

FPD = flushes per day
FPDPP = flushes per day per person
FTE = full-time equivalent, 1 for one person per 8 hour shift; visitors are calculated as daily average visitors
GPD = gallons per day
GPF = gallons per flush
GPM = gallons per minute
GPU = gallons per use
GPV = gallons per visit
IE = irrigation type
K_D = density factor
K_{MS} = microclimate factor
K_L = landscape factor
K_S = species factor
KW = 3413 Btu
MPU = minutes per use
Therm = 100 ft^3 (100,000 Btu) of gas
TWA = total water applied
TWPA = total potable water applied
UPD = use per day
WCM = water conservation measure

SUPPORTING CHARTS AND TABLES



0.5	0.7	0.9	1.3	1.8	3.0	4.0	9.0	18.0	25.0	36.0	Liter/Hour
12.0	16.8	21.6	31.2	43.2	72.0	96.0	216.0	432.0	600.0	864.0	Liter/Day
4.4	6.1	7.9	11.4	15.8	26.3	35.0	78.8	157.7	219.0	315.4	m^3/Year
0.1	0.2	0.2	0.3	0.5	0.8	1.1	2.4	4.8	6.6	9.5	Gallons/Hour
3	4	6	8	11	19	25	57	114	159	228	Gallons/Day
1,157	1,620	2,083	3,009	4,166	6,943	9,258	20,830	41,659	57,860	83,318	Gallons/Year

Figure F-1 Water Losses due to Leaks in Fittings of Domestic Installations
Adapted from VDI (2000)

Table F-1 Water Losses at 5 Bar (72.5 psi) Pressure due to Leaking Pipes

Opening, in. (mm)	gpm (L/s)	gph (L/h)	gpd (m^3/day)	gal/month (m^3/month)	acre ft/yr (m^3/yr)
0.02 (0.5)	0.08 (0.005)	5 (18)	114 (0.04)	3472 (13)	0.13 (158)
0.04 (1.0)	0.25 (0.016)	15 (58)	365 (1.40)	11,109 (42)	0.41 (508)
0.06 (1.5)	0.48 (0.030)	29 (108)	685 (2.60)	20,830 (79)	0.77 (946)
0.08 (2.0)	0.84 (0.053)	50 (191)	1210 (4.60)	36,799 (139)	1.36 (1673)
0.10 (2.5)	1.35 (0.085)	81 (306)	1940 (7.30)	59,017 (232)	2.17 (2680)
0.12 (3.0)	2.16 (0.136)	129 (490)	3104 (11.80)	94,427 (358)	3.48 (4292)
0.14 (3.5)	2.98 (0.188)	179 (677)	4291 (16.00)	130,532 (487)	4.81 (5842)
0.16 (4.0)	3.92 (0.247)	235 (889)	5638 (21.30)	171,496 (649)	6.32 (7787)
0.18 (4.5)	4.82 (0.304)	289 (1094)	6939 (26.30)	211,073 (799)	7.77 (9583)
0.20 (5.0)	5.90 (0.372)	354 (1339)	8492 (32.10)	258,286 (978)	9.51 (11,730)
0.22 (5.5)	6.88 (0.434)	413 (1562)	9907 (37.50)	301,334 (1104)	11.10 (13,683)
0.24 (6.0)	7.93 (0.500)	476 (1800)	11,413 (43.20)	347,159 (1314)	12.78 (15,768)
0.26 (6.5)	8.99 (0.567)	539 (2041)	12,943 (49.00)	393,678 (1490)	14.50 (17,879)
0.28 (7.0)	10.38 (0.655)	623 (2358)	14,952 (56.60)	454,778 (1722)	16.75 (20,659)

Source: VDI (2000)

Correction factors for different pressures:

0.5 Bar (7.25 psi)—Add 26%
1.0 Bar (14.5 psi)—Add 45%
2.0 Bar (29.0 psi)—Add 63%
3.0 Bar (43.5 psi)—Add 77%
4.0 Bar (58.0 psi)—Add 89%
5.0 Bar (72.5 psi)—Add 100%
6.0 Bar (87.0 psi)—Add 108%
7.0 Bar (101.5 psi)—Add 118%
8.0 Bar (116.0 psi)—Add 125%
9.0 Bar (130.5 psi)—Add 132.5%
10.0 Bar (145.0 psi)—Add 140%

"Standard"?

Table F-2 Water Use Standards

Item	Water Flow (Gallons)					Usage					
	Std Pre 1990	Std	EP Act 1997	Low Post 2000	Unit	Male Use	Female Use	Male Visitor Use	Female Visitor Use	Units	Cleaning
Symbol		S	L	VL		M	F	MV	FV		C
Sanitation											
Water closet tank type	4.5[a]	3.5[a]	1.6[a]	1.0[a]	gpf	1.0[b]	3.0[b]	0.1[b]	0.5[b]	fpdpp	1
Water closet dual flush tank type (low flush)		1.6[a]	1.1[a]	0.8	gpf	1.0[b]	2.0	0.1[b]	0.5[b]	fpdpp	1
Water closet flush valve	4.5[a]	3.5[a]	1.6[a]	1.0[a]	gpf	1.0[b]	3.0[b]	0.1[b]	0.5[b]	fpdpp	1
Water closet flush valve dual flush type (low flush)		1.6[a]	1.1[a]	0.8	gpf	1.0[b]	2.0	0.1[b]	0.5[b]	fpdpp	1
Urinal	3.5[a]	1.5[a]	1.0[a]	0	gpf	2.0[b]		0.4[b]		fpdpp	1
Urinal high efficiency (HEU)		1.0	1.0[a]	0.5	gpf	2.0[b]		0.4[b]		fpdpp	1
Lavatory faucet (cold water only)	6.0[a]	4.0[a]	2.5[a]	0.5[a]	gpm	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Lavatory faucet (tempered chilled-water component)	3.0	2.0	1.25	0.25	gpm	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Lavatory faucet automatic (cold water only)		1.0	0.25[a]	0.25[a]	gpv	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Lavatory faucet automatic (tempered CW component)		0.5	0.13	0.13	gpv	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Sink faucet (cold water only)	2.5	2.5	1.0	1.0	gpm	1.0[b]	1.0[b]			upd	0.5
Sink faucet (tempered)	1.25	1.25	0.5	0.5	gpm	1.0[b]	1.0[b]			upd	0.5
Shower (cold water only)	6.5[a]	3.5[a]	2.5[a]	1.5[a]	gpm	0.1[b]	0.1[b]			upd	0.5
Shower (tempered)	3.25	1.75	1.25	0.75	gpm	0.1[b]	0.1[b]			upd	0.5
Trap primer	4.0[c]	0.5[d]	0.5[d]	0.5[d]	gpd						
Hot Water											
Lavatory faucet (hot water only)	6.0[a]	4.0[a]	2.5[a]	0.5[a]	gpm	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Lavatory faucet (tempered hot-water component)	3.0	2.0	1.25	0.25	gpm	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Lavatory faucet automatic (tempered hot-water component)		0.5	0.13	0.13	gpv	3.0[b]	3.0[b]	0.5[b]	0.5[b]	upd	0.5
Sink faucet (hot-water only)	2.5	2.5	1.0	1.0	gpm	1.0[b]	1.0[b]			upd	0.5
Sink faucet (tempered hot-water component)	1.25	1.25	0.5	0.5	gpm	1.0[b]	1.0[b]			upd	0.5
Shower	6.5[a]	3.5[a]	2.5[a]	1.5[a]	gpm	0.1[b]	0.1[b]			upd	0.5
Shower (tempered hot-water component)	3.25	1.75	1.25	0.75	gpm	0.1[b]	0.1[b]			upd	0.5
Clothes washer (residential)		50	45	25	gpu	1.0	1.0			upd	
Dishwasher (residential)		13	13	6	gpu	0.2	0.2			upd	

[a] FEMP (2002)
[b] USGBC LEED WE
[c] ASHRAE (2010a), Figure 5.1 (1 drop per second)
[d] ASHRAE (2010a), Figure 5.1 (1 drop every 8 seconds)
[e] Tempered water calculated as 50% hot water to 50% chilled water
[f] kW per 1,000 gallons of water

Some of these units are written in all caps in your preceding list of nomenclature. Should these be changed here or in the nomenclature so they all match?

Appendix G

Instruments for IEQ Thermal Comfort Measurements

INSTRUMENTS FOR PHYSICAL MEASUREMENTS

For flexibility, measurements are taken with handheld instrumentation with immediate readout. The instruments are professional grade but are at the inexpensive end of the cost spectrum. The most common measurements and the instruments used to take them are listed below, along with the average price ranges for the instruments.

- *Air temperature:* Portable thermometer, with external element on a wire, shielded from radiation, sensitive to 0.5°C (1°), with a one-minute 90% response time ($50).
- *Humidity:* Electronic psychrometer (Figure G-1) or sling psychrometer, sensitive to 5% RH ($50–$500).
- *Radiation:*
  - Mean radiant temperature and operative temperature—indices that combines the effects of air temperature and radiant temperature on a person—can both be obtained from an inexpensive globe thermometer (Figure G-2, $100). A 38 mm table tennis ball painted primer grey provides the most quickly responding globe. Globe thermometer results should be corrected for air speed when air movement is high (McIntyre 1980), but in most indoor situations the globe temperature output can be used as a direct measure of operative temperature.
  - Radiant temperature asymmetry can be obtained by sequentially placing a reflective sheet (aluminum or aluminized mylar) on either side ~~of~~ an unshielded thermometer and determining the difference in the observed temperatures. The well-established commercial meter for this, the LumaSense Plane Radiant Temperature sensor, costs $2000 and is part of a thermal comfort data logger system (Innova 1221) that costs $50,000.
  - Surface temperatures are typically measured with an infrared gun or surface probe (Figures G-3 and G-4, $20–$100).
  - Handheld infrared cameras can be used to take infrared photos of an environment to visually map hot and cold surfaces in a space (Figure G-5, $4500–$6500).
  - The potential for direct solar gain at a workstation at any time of the year can be predicted by fish-eye-based optical devices (Figure G-6,

$300–$1300) and software for plotting sunpaths on fish-eye photographs (free to $1000).
    - Spot measurement of solar gain into an occupied space can be obtained with a shortwave-spectrum pyranometer (Figure G-7, $675).
- *Air speed:* Handheld anemometer, sensitive downward to 0.10 m/s (Figure G-8, $500–$700), with smoke tube or chalk-dust puffer for airflow visualization ($100).

Figure G-1 Psychrometer for Measuring Temperature and Humidity
Source: Fluke Corporation

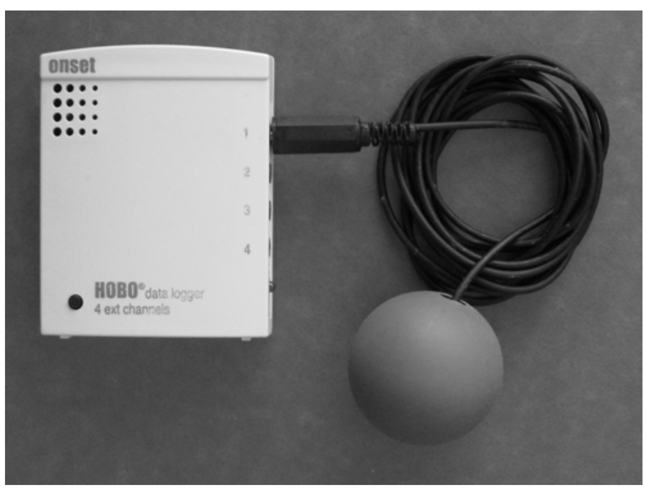


Figure G-2 Globe Thermometer Attached to Temperature Data Logger
Source: Center for Built Environment

Figure G-3 Infrared Surface Temperature Spot Meter
Source: Fluke Corporation

Figure G-4 Infrared Surface Temperature Probe with 90º Cone of Acceptance
Source: Center for the Built Environment

Figure G-5 Infrared Camera for Measuring and Visualizing Surface Temperatures
Source: Flir Systems

Figure G-6 Fisheye Camera Device for Predicting Annual Sunpaths at a Given Point Indoors
Source: Solmetric Corporation

Figure G-7 Pyranometer for Measuring Solar Radiation
Source: LI-COR Biosciences

Figure G-8 Hot Wire Anemometer
Source: Control Company

SOFTWARE FOR PHYSICAL MEASUREMENTS

Physical measurements are also sometimes available from the facility's building automation system (BAS). They usually include thermostat settings, zone supply air temperatures and return temperatures, and flow settings. These values may be accessed with the UT software (PEC 2012). The BAS data can be merged in various ways with the above measurements of the thermal environment to produce a more complete picture of the building performance over time.

Appendix H
Additional Resources for IEQ IAQ

H

BUILDING AIRFLOW MODELS

In situations where it is beneficial to have a detailed understanding of the airflows in a building it is possible to construct models with as much detail as is needed. These are generally first developed at the time of construction or major renovation; however, there are some potential uses later, after there have been changes in physical layout or use. The initial models may be created before the building is constructed, but at the time of commissioning and before occupancy permits are issued there may be measurement sets that are needed to verify the adequacy of the model under the as-built and as-operated conditions. These measurement plans may be the basis for a measurement plan that is needed when these models are updated later in the life of the building as a result of geometry or usage changes. These are discussed by Firrantello et al. (2007).

TYPES OF MODELS

COMPUTATIONAL FLUID DYNAMICS

The most detailed type of model is a computational fluid dynamics (CFD) model in which at each three-dimensional node in the space the air movement and species concentrations (particulate and chemical) are calculated on either a steady-state or time-dependent basis. Many vendors provide CFD packages that are used mostly during the building design phase. The building or space geometry is sometimes conveniently entered by connection to computer-aided design (CAD) programs used in the design software suite. If the building or space already exists, then the calculation can be calibrated or anchored by measurements made at the spatial limits and/or by the use of assumed boundary conditions. While this type of calculation provides maximal detail, the setup and execution can be time consuming. The work generally has to be performed by highly trained specialists. For some codes there are macro features that permit the easy introduction of standard HVAC components such as diffusers, filters, fans, etc. The computational intensity is high enough that the analysis of entire buildings is seldom undertaken. Generally, it is limited to a single room and its immediately connected space. The measurement plan that is needed to qualify a CFD model is best developed in conjunction with the modeler. After convergence, the CFD results may need to be compared with internal measurements, such as, for example, stratification profiles, to verify the correctness of the results.

NETWORK MODELS

Where the time and effort of CFD is not justified and a somewhat less accurate solution is acceptable, network models may be used. The CONTAM program developed by National Institute of Standards and Technology (NIST 2012) is one of the prominent ones. These models are computationally much less intensive, but the simplifying assumption is that within each computational volume the conditions are uniform. This is generally within each room of a building. For a large room such as an atrium where it is likely that significantly different conditions exist within it, some additional detail may be generated by the inclusion of false partitions that freely let mass pass through them. This allows the adjacent volumes to have different temperatures, pressures, and/or species calculations. The setup of the zonal geometry and all the potential leakage paths can still be time consuming. Assumptions must be made about the amount of air leakage associated with inferior partitions. Network models have been used to model airflows in buildings that have thousands of internal zones. To ease setting up the problem as well as provide a way to calibrate them for existing buildings, specialty versions of CONTAM have been developed. For example, The Pennsylvania State University developed CONTAM PCW (Firrantello et al. 2007), a software tool that identifies a set of simple measurements to confirm airflow predictions, which can then be used to refine the building model. The software provides model-tuning techniques and an enhanced, easier-to-use interface; large-scale building airflow tests have been conducted to validate the model.

USES OF AIRFLOW MODELS

The model developed when a building or space was designed may have to be updated when a significant change is made to the geometry, thermal characteristics, or particulate or chemical sources. A new model may have to be developed for the first time during the building lifetime in response to the need to solve a problem. Ventilation systems that rely on buoyancy are particularly susceptible to changed airflow patterns when other changes are made.

SMOKE CONTROL SYSTEMS

The design of performance-based systems can call for the development of an airflow model. For example, first cost may be lowered when designing the smoke control system for an atrium. While the cost of developing such a model will be an addition, the reduced number of components needed by a performance-based design may result in sufficient savings to justify it. Inspection should be done periodically to determine if material changes have been made that would require updating and recommissioning of a performance-based system. If such changes have been made, it would be best practice to update the model to reverify the system performance. This will require an updated measurement plan similar to what was used at design time.

BUOYANCY-DRIVEN FLOWS

Tall buildings require special consideration due to the stack effect. The buoyancy differences between indoor and outdoor air that arise from temperature differences and building height lead to internal airflows driven by pressure differences. Configuration changes that open additional leakage paths can lead to unintended consequences. Surface pressures can develop that are beyond what was expected initially and, for example, doors and elevator doors can have difficulty opening or closing. While these can lead to seasonal thermal comfort or mechanical issues, they also change ventilation effectiveness due to changes in the distribution of ventilation and supply air from the original design. An airflow model can be helpful in developing remedial solutions, but a measurement plan will probably be needed to determine the direction and possibly also the magnitude of flows in the involved connecting areas, such as doorways and hallways, to calibrate the model.

LIFE-SAFETY SYSTEMS

Laboratory and industrial spaces may involve the use of hazardous chemicals or biohazards in their regular operation. Safety regulations may require strict pressure differentials between the normally occupied areas and the areas involving the chemicals to guarantee unidirectional flow. Periodically, airflow models may need to be updated as physical changes are made to the space, the ventilation, or the exhaust systems. Challenge experiments may be particularly useful in proving the continuing adequacy of the design. In such experiments, a release of a nontoxic surrogate moiety may be made and its transport may be followed over time during system operation. A pulse injection of extra carbon dioxide or (with approval from cognizant authorities) an inert and highly detectable gas such as sulfur hexafluoride may be used.

ENVIRONMENTAL MONITORING APPENDIX FROM *INDOOR AIR QUALITY GUIDE*

This section provides the full text of Appendix A from *Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* (ASHRAE [2009a]; reprinted with permission). For this information to integrate smoothly into this Guide, the figure, table, and reference numbering have been modified from the original; otherwise the content remains as originally published.

EXCERPT

Environmental Monitoring

A wide variety of environmental monitoring methods are available to evaluate the quality and/or acceptability of the indoor environment. However, conducting such monitoring is not always needed or even advisable and is extremely challenging for a variety of reasons. This appendix is intended to provide design professionals with an understanding of these complexities in order to better appreciate these challenges. Factors to keep in mind when considering environmental monitoring include

- the selection of the contaminants to be measured;
- the selection of testing equipment and protocols;
- the location, timing, duration, and accuracy of the tests;
- the training, bias, and competency of the investigator;
- appropriate controls or reference values to which the results can be compared; and ultimately
- the purpose of the evaluation.

Misunderstanding of these factors occurs even by experienced professionals, resulting in the monitoring contributing little useful information—or worse, leading to erroneous conclusions and ill-advised actions.

Key Points Regarding Environmental Monitoring of IAQ

- Never measure anything unless the purpose of environmental monitoring has been clearly established and you know what you are going to do with the results. The specific target pollutants that will be measured and the reference concentrations that will be used for interpreting the results need to be defined before the monitoring and must fulfill the intended purpose for the monitoring effort.
- Short-term, localized measurements represent the conditions only at the place and time the sample is collected and cannot be assumed to represent the building more generally. Monitoring needs to cover a range of times and building operational and use conditions to enable a meaningful characterization of IAQ.
- Airborne concentrations of indoor-source pollutants are strongly dependent on concurrent outdoor air ventilation rates. Only by simultaneously measuring ventilation can concentration results be interpreted correctly, particularly variations over time.
- While it would be ideal to have a simple and easily used metric to quickly and inexpensively establish the acceptability of the IAQ, no such metric exists due to the wide range of pollutants in indoor air and the lack of knowledge regarding human responses to most pollutants and pollutant mixtures.

Indoor Air Characteristics

Many of the challenges associated with indoor air sampling are due to the characteristics of indoor air pollution. This section briefly describes some of these characteristics.

Indoor Air is a Complex Mixture

The chemicals that are commonly present in indoor air generally include scores or even hundreds of compounds at widely varying concentrations from parts per trillion to parts per thousands. The two main constituents of air at sea level are nitrogen (about 78%) and oxygen (about 21%), along with 0.038% carbon dioxide (CO_2), trace amounts of other gases, and a variable amount (around 1%) of water vapor. The compounds present in air that are of interest to IAQ include chemicals, particles, and microbial components, as shown in Table H-1.

Use Environmental Monitoring Sparingly

Most experts agree that when investigating IAQ problems, environmental monitoring should only be employed late in the process. Interviews, building walk-throughs, and establishing the history of the problem(s) are the first steps. If necessary, follow-up steps include review and evaluation of building plans and specifications, review of operational logs, and establishment of initial hypotheses regarding the potential causes of the problem. The hypotheses can point toward specific pollutants that could or should be measured. Finally, monitoring of ventilation system performance, outdoor air delivery rates, thermal conditions, and a set of target pollutants may be warranted.

Carefully Consider Where Samples are Taken

Given the variation in concentrations typically seen in buildings, it is important to be careful in selecting air sample locations. Some factors to consider include building layout in terms of activities and occupancy patterns, HVAC system zoning, and locations of complaint and noncomplaint areas.

Table H-1 Broad Categories of Indoor Air Pollutants

Constituent	Detailed Categories
Chemicals*	Organic • Volatile • Semi-volatile Inorganic
Particles—defined by size	Total suspended particles <100 µm mass median aerodynamic diameter Respirable suspended particles <10 µm mass median aerodynamic diameter Fine particles <2.5 µm mass median aerodynamic diameter
Biological aerosols (Bioaerosols)**	Fungi, mold Bacteria Viruses Pollen

* Chemicals may be in the solid (condensed) phase or the gaseous phase. Gases can be molecules in the air or on surfaces, including the surfaces of airborne or settled dust and other particles.

** Bioaerosols may be viable or nonviable.

Indoor air sampling presents challenges in terms of obtaining samples that represent occupant exposures. Sample collection too close to the occupants will be influenced by the occupants' activities and metabolic products. On the other hand, sample collection too far from the occupants will not capture the occupants' actual pollutant exposures, particularly those that are dominated by the occupants' own activities.

Consider Source Strength and Ventilation when Interpreting Results

As noted previously, indoor concentrations are strongly dependent on outdoor air ventilation rates and source strengths. This relationship is defined by the following equation, which describes how the indoor concentration is impacted by ventilation and source strength at steady-state and zero outdoor concentration:

$$C = EF/Q$$

where

C = pollutant concentration

EF = pollutant source strength (amount of pollutant emitted per unit time, in some cases also per unit of area of the source)

Q = outdoor air ventilation rate of the space

Figure H-1 contains plots of this relationship for three different source strengths, demonstrating the importance of source strength and ventilation in determining concentrations. While low ventilation rates can lead to very high concentrations, note that once the ventilation is high enough to reduce the concentration, further increases in ventilation have little impact on absolute concentration.

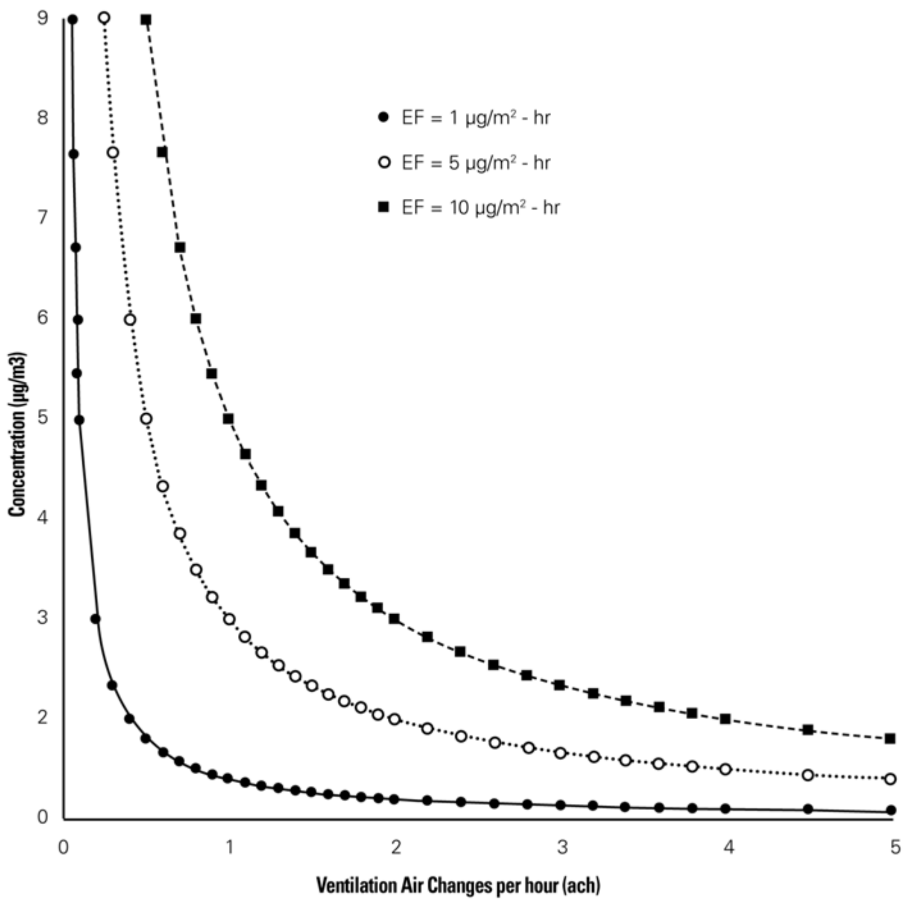


Figure H-1 Relationship of Source Strength, Ventilation, and Pollutant Concentration

On the other hand, reducing the source strength can achieve significant concentration decreases at the lower end of typical building ventilation rates.

Only by simultaneously measuring ventilation can concentration results be interpreted, particularly variations over time in these concentrations. If the monitoring effort is to be used to calculate source strengths, then ventilation rate measurements are essential.

Time Period of Monitoring

For long-term sampling—hours to days—results are usually given in time-weighted averages that represent time-integrated (average) exposure over the total duration of the monitoring. These results are useful for assessing average or cumulative exposure. However, they fail to capture variations in concentrations or source strengths during the time covered.

Short-term samples such as "grab samples" collect air over a very short period of time and can capture a peak exposure if the time the sample was taken is coincident with peak concentrations. However, since source strengths and ventilation vary over time and space, a grab sample may not provide an indication of average, long-term concentration.

Sampling Methods Determine and Limit What can be Measured

Sampling and analysis can only detect what the method is capable of detecting. Most methods are relatively limited and have interferences and biases that must be considered when interpreting results. For example, the results of all VOC samplings are dependent on the methods used, and the results obtained with different methods should not be compared without abundant caution. Even the very best sampling technology is incapable of detecting all organic compounds of interest. Noteworthy for their usual absence from indoor air sampling and their potential health impact are the semi-volatile organic compounds (SVOCs) including pesticides, plasticizers, and fire retardants.

Some sampling methods that are more general than specific in terms of what they measure can be useful for comparisons where the measurement objective is to determine whether conditions in the building have changed. The most common general methods are the measurement of total volatile organic compounds (TVOCs) and the measurement of total colony-forming units, which are both the sum of those compounds or organisms, respectively, that the method used is capable of detecting. However, no methods are capable of collecting all TVOCs or colony-forming units. Furthermore, the lack of information about the species of organic compounds or microorganisms prevents the results from being useful for understanding potential health or comfort implications of exposure and can even result in erroneous interpretations and inappropriate actions. Only by identification and quantification of specific compounds or organisms can there be any health or comfort assessment of the monitoring results.

Particle measurements are also commonly reported as the sum of all sampled particles or of those in a particular size range, e.g., total suspended particles, particles less than 10 μm in diameter (PM10), and particles less than 2.5 μm in diameter (PM2.5). Even within a particular size range, particles can be widely varying in important, health-effects-relevant characteristics including their chemical compositions, their sizes and shapes, and the chemicals that may be adsorbed to their surfaces.

Pollutants with Outdoor Sources

Some indoor pollutants have primarily or only outdoor sources, some have only or predominantly indoor sources, and most have both indoor and outdoor sources. For those that have both indoor and outdoor sources, simultaneous measurements need to be made both indoors and outdoors in order to understand the results.

Knowing What to Do with Results

Monitoring should never be done unless there is knowledge about what will be done with the results. This presents challenges for indoor environmental monitoring because of the lack of sufficient information about the health impacts of most indoor pollutants. There is an important deficiency in terms of standards and guidelines regarding safe or acceptable concentrations of indoor air pollutants. Several available guidelines and standards are documented in Appendix B of ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2007d).

An alternative to comparing concentrations to health and safety regulations, guidelines, or standards is to compare them to what is commonly found in similar buildings. Two databases of indoor pollutant measurements include the U.S. Environmental Protection Agency (EPA) BASE study (EPA 2006) and Hodgson and Levin (2003).

Measurement of Specific Pollutants

Standardized methods for measuring indoor air pollutants are limited in the pollutants covered, but many are available from several sources, such as the following.

- ASTM Subcommittee D22.05 on Indoor Air Quality (ASTM 2009)—www.astm.org/COMMIT/SUBCOMMIT/D2205.htm
- *ASTM Standards on Indoor Air Quality*, Third Ed. (ASTM 2007b)—www.astm.org/BOOKSTORE/COMPS/179.htm
- National Institute of Occupational Safety and Health (NIOSH)—www.cdc.gov/niosh
- EPA Indoor Air Quality Publications and Resources (EPA 2009)—www.epa.gov/iaq/pubs/
- *Recognition, Evaluation and Control of Indoor Mold* (AIHA 2008), American Industrial Hygiene Association (AIHA)—www.aiha.org
- American Conference of Governmental Industrial Hygienists (ACGIH)—www.acgih.org

Carbon Dioxide—The Most Measured Gas in Indoor Air

Carbon dioxide (CO_2) is not a pollutant per se when measured at typical indoor concentrations. It is usually used as a surrogate for the adequacy of ventilation in relation to human occupancy. While the relationship between building ventilation rates and indoor CO_2 is well understood (Persily 1997; ASTM 2007a; Mudarri 1997), measurements of CO_2 in indoor air are commonly misapplied and misinterpreted. These references need to be consulted before conducting such measurements.

Appendix I

Lighting/Daylighting Verification Workbook and

We need an introductory paragraph here rather than a list of sections.
Space Details Worksheet
Lighting Inventory Worksheet
Forms for Illuminance Measurements
Forms for Luminance Measurements
Recommended Illuminance Levels
Discussion of Measurement Instrumentation

SPACE DETAILS WORKSHEET

Get form from Basic+Diagnostic Level Lighting Workbook

LIGHTING INVENTORY WORKSHEET

Get form from Basic+Diagnostic Level Lighting Workbook

ILLUMINANCE MEASUREMENTS FORM

Get form from Basic+Diagnostic Level Lighting Workbook

ILUMINANCE MEASUREMENTS FORM

Get form from Basic+Diagnostic Level Lighting Workbook

SUPPORTING INFORMATION

RECOMMENDED ILLUMINANCE LEVELS IN TYPICAL SPACE TYPES

The values shown in Table I-1 (in footcandles; multiple by 10.76 to get lux) are recommendations from the Illuminating Engineering Society of North America (IES) and are subject to the specifics of the actual application and its environment. They are provided in this Guide to assist in benchmarking measurements made at the Diagnostic Measurement level. However, the areas and tasks shown in the table are just a few of the many possible situations that could be encountered. For a complete list, see *The Lighting Handbook* (IES 2011).

Table I-1 Recommended Illuminance Levels

Application	Horizontal[1,3]	Vertical[2,3]
Interior Spaces		
Auditorium		
Assembly	10	
Social activity	5	3
Conference Room		
Meeting	30	7.5
Video conference	30	30
Educational Facilities		
Corridors	20	10
Classrooms (typical)	50[4]	30
Lockers	10	3
Food Service		
Cashier	30	3
Kitchen/food preparation	50[4]	20
Pantry	30	3
Retail/Malls		
Dressing room	30	5
Circulation	10	
General displays	50[4]	10
Feature displays	100[4]	30
Point of transaction	30	
Main concourse	30	5
Kiosks	100[4]	30
Service corridors	30	
Offices		
Open—high VDT use	30	5
Open—medium VDT use	50[4]	5
Private office	50[4]	5
Lobby (general)	10	3
Filing	30	20
IT/programming	10	7.5
Lunch/break room	10	3
Service Spaces		
Stairways	10	5
Corridors	5	
Restrooms	10	
Equipment room	20	15
Shipping and receiving	30	10
Storage/active	30[4]	
Storage/inactive	5[4]	
Vestibule	10	

Application	Horizontal[1,3]	Vertical[2,3]
Industrial Spaces[4]		
Raw Material Processing		
Course	10	
Medium	30	
Fine	50[4]	
Very fine	100[4]	
Component Manufacturing		
Large	30	
Medium	50[4]	
Fine	100[4]	
Assembly and Inspection		
Simple	30	
Difficult	100[4]	
Exacting	300+[4]	
Exterior Spaces		
Building Entrances		
Active	5	3
Inactive	3	3
Loading platform	10	3
Storage Yards		
Active	10	3
Inactive	1	0.3
Reading Tasks		
Handwritten Tasks		
#3 pencil	50[4]	
#4 pencil	100[4]	
Ball-point pen	30	
Whiteboards		5
Chalkboards		50[4]
Printed Tasks		
6-point type	50[4]	
8/10-point type	30	
Glossy magazines	30	
Maps	50[4]	
Newsprint	30	
Typed originals	30	
Telephone books	50[4]	

1. Recommended average horizontal illuminance over the entire workplane at the height of the task; e.g., for reading, 2.5 ft (0.76 m) is typically used, while for circulation areas the floor height is used.
2. Recommended average vertical illuminance. Should be calculated /and/or measured in the orientation of known vertical planes of the task, such as on the face of a whiteboard; otherwise use an average of four calculations (one in each cardinal direction).
3. These values should be cut in half when more than 50% of the regular occupants are expected to be under the age of 25 and should be doubled when more than 50% of the regular occupants are expected to be over the age of 65.
4. To be calculated/measured in the immediate task area only.

EQUIPMENT USED IN LIGHTING/ DAYLIGHTING MEASUREMENTS

Illuminance Meters

Illuminance meters can be rack mountable, benchtop, or portable. Typically the detector and filter are remotely connected via cable to the amplifier and display. See Figure I-1 for an example of an illuminance meter.

Table I-2, extracted from CIE Publication No. 69 (CIE 1987) by the International Commission on Illumination (CIE), contains a summary of expected errors for illuminance meters for the best commercially available meters. Of particular importance is the need to choose a meter with the best V(l) match so as to best match the human vision system.

Two issues of particular concern when making illuminance measurements include the cosine effect and leveling.

- *The cosine effect:* At grazing angles (where the light is entering the meter at a large angle when measured from the normal to the meter face) can be reflected by the optics of the meter. At such angles readings can be as much as 25% below the true illuminance. This can be corrected by aiming the meter at the light source and then multiplying the value read by the cosine of the aimed angle from the normal of the meter facing in its original position. See CIE Publication No. 69 for additional discussion on this topic.

Figure I-1 Illuminance Meter
Reproduced by permission of Acuity Brands Lighting, Inc.

Table I-2 Expected Errors for Illuminance Meters

Characteristic	Representative Error Value
V(l) Match (f_1’)	2%
Ultraviolet response	0.2%
Infrared response	0.2%
Cosine response	1.5%
Linearity error	0.2%
Fatigue	0.2%
Polarization	2%

Source: CIE (1987)

- *Leveling:* When one or just a few light sources are in the space being measured, it is important to ensure that the meter is truly level. In critical situations instruments are available in which the detector is gimbal mounted and self-leveling. However, these are typically used in measuring exterior areas.

Luminance Meters

Luminance meters are essentially illuminance meters with the addition of suitable optics to image the target area onto the detector. The user is typically able to view the target and surrounding areas. Such devices allow the user to observe and measure areas subtending just a few seconds of arc to several degrees. (See Figure I-2.)

Table I-3, extracted from CIE Publication No. 69, contains a summary of expected errors for luminance meters for the best commercially available meters.

Figure I-2 Luminance Meter
Reproduced by permission of Acuity Brands Lighting, Inc.

Table I-3 Expected Errors for Luminance Meters

Characteristic	Representative Error Value
V(l) Match (f_1’)	3%
Ultraviolet response	0.2%
Infrared response	0.2%
Errors of focus	0.4%
Linearity error	0.2%
Fatigue	0.1%
Polarization	0.1%
Directional response	2%
Effect from the surrounding field	1%

Source: CIE (1987)

Appendix J
Acoustics Verification Worksheets and Resources

DIAGNOSTIC MEASUREMENT

INSTRUMENTS FOR PHYSICAL MEASUREMENTS

Acoustic measurements at the Diagnostic Measurement level should be made using instrumentation equivalent to an integrating sound level meter equipped with an omnidirectional condenser microphone (Figure J-1). The meter should meet, at a minimum, Type 2 specifications according to ANSI S1.4 (2006) and be capable of digitally displaying the A-weighted equivalent sound level (L_{eq}) to the nearest decibel. The manufacturer's stated noise floor of the sound level meter should not be higher than 25 dB(A).

The cost of a sound level meter and calibrator meeting the specifications above will range from $2000 to $3000. Annual calibration will be an additional cost of $200 to $500. The time required to conduct these measurements will depend on the size of the space and the variability of the sound within the space. Each measurement can be made in a matter of minutes. An equal amount of time will be required for documentation.

Figure J-1 Low-Cost, Integrating Sound Level Meter

Reproduced by permission of Bruel & Kjaer Instruments

SOUND LEVEL MEASUREMENTS EXAMPLES

Example worksheet is from Acoustics Worksheets-Forms Examples.xlsx. These are the two Sound Level Measurement Worksheets.

Diagnostic sound level measurements are recorded in the Sound Level Measurements worksheet in the Diagnostic+Advanced Level Acoustics Workbook. Examples of this worksheet are shown in Figures J-2 and J-3, and a blank sheet is included on the companion CD. The worksheet lists each room or space that is identified at the Basic Evaluation level as requiring further diagnostic measurements. In the worksheet, when the room/activity is selected from the drop-down menu, criteria for background noise and room reverberation time (T_{60}) are automatically populated. Otherwise the user may overwrite the menu selections and insert the room/activity and criteria. Actual room reverberation times may be estimated using the T_{60} calculator detailed in the following section. Observations during the measurements should be noted in the comments column on the worksheet.

Acoustic measurements and criteria can vary significantly with the building's use. Example Sound Level Measurement worksheets are shown for an office building and school. A blank worksheet is included on the companion CD.

Figure J-2 Example Sound Level Measurements Worksheet for an Office Building

Figure J-3 Example Sound Level Measurements Worksheet for a School Building

SIMPLIFIED METHOD TO EVALUATE ROOM REVERBERATION TIME (T_{60})

Example worksheet is from Acoustics Worksheets-Forms Examples.xlsx. This is the Reververation (T60) Calculation Worksheet.

A simple method for evaluation of room reverberation time (T_{60}) is presented here. The calculations are performed in the Reververation (T_{60}) Calculation worksheet in the Diagnostic+Advanced Level Acoustics Workbook. This worksheet is provided in the companion CD. A separate sheet is required for each room. The calculated reverberation time in all octave bands, from 250 to 4000 Hz, should be compared with the T_{60} criteria in Table 3-2 of this Guide, with the exception of classrooms, where the 500 to 2000 Hz octave bands should be compared with the T_{60} criteria. An example reverberation calculation worksheet for a classroom is shown in Figure J-4, and a blank worksheet is provided on the companion CD.

Figure J-4 Example Reverberation Calculation Worksheet

SIMPLIFIED EVALUATION OF OFFICE SPEECH PRIVACY

A simple field-test method is presented here that can be used to screen for speech privacy issues in offices. It is based on selecting the expected voice level of the typical talker, measurement of the background noise level at the listener's location in dB(A) sound level, and measurement of the noise reduction between the talker and the listener in the work spaces.

The speech privacy method is based on the work of R. Young, first published in 1965 and more recently confirmed by C. Salter for Center for the Built Environment (CBE 2012). This method has not yet received consensus approval by a recognized standardization organization and, for this reason, is included here for information only. It can provide a reasonable estimate of the speech privacy for normal-hearing young adults for whom English is the primary language. Figure J-5 illustrates the concept.

The instrumentation required for this screening method consists of a sound level meter of the type used for the diagnostic measurements to measure the background noise at the listener's location and a portable loudspeaker (with adequate amplification) and with an audio source (pink noise for open plan, white noise for

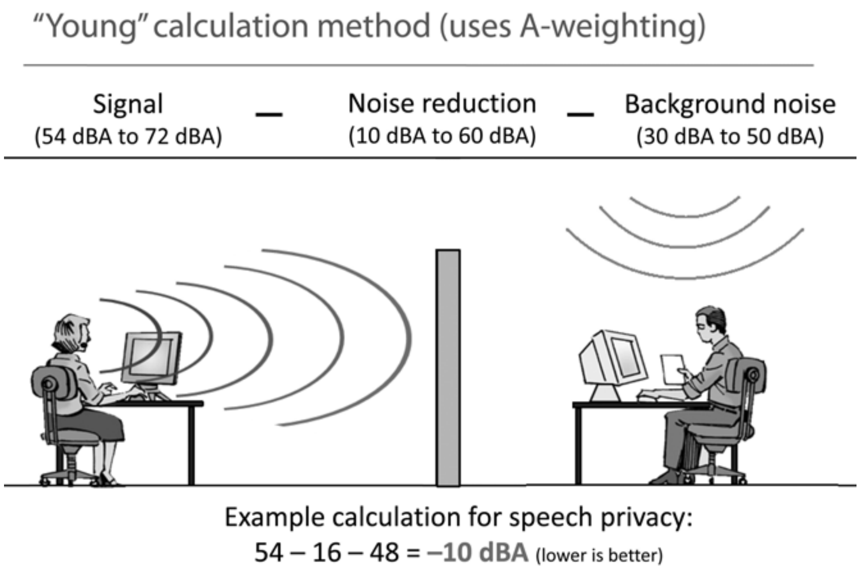


Figure J-5 Simplified Speech Privacy Measurement
Source: Center for the Built Environment (2011)
Reproduced by permission of Charles M. Salter Associates

closed plan) to measure the noise reduction between the talker's location and the listener's location. The speaker used for the open-plan measurement should be somewhat directional (+10 dB forward) to represent a person's typical head directivity, whereas the closed-plan speaker should be more or less omnidirectional (uniform directivity).

The signal-to-noise ratio is calculated as follows:

Talker Voice Level – Noise Reduction – Background Noise = Signal to Noise

where the anticipated Talker Voice Level may be characterized as:

Speaker Voice Level	L_{eq} dB(A)
Low	54
Normal	60
Raised	66
Loud	72

The resulting level of speech privacy is estimated according to the effective signal-to-noise ratio as follows:

Speech Privacy	Signal to Noise
Confidential	–15
Normal	–9
Marginal	–3
Unacceptable (or good speech intelligibility)	0

The speech privacy (and conversely, the speech intelligibility) depends on the measured background noise and architectural system noise reduction. Both of these measurements are made with a simple A-weighted sound pressure level meter.

ADVANCED ANALYSIS

INSTRUMENTS FOR PHYSICAL MEASUREMENTS

For Advanced Analysis, acoustic measurements should be performed in octave bands, which are then used to determine metrics such as noise criteria (NC) ratings (see Figure J-6). The instrumentation should meet Class 1 sound level meter requirements as defined in IEC 61672-1 Ed. 1.0 b:2020 or Type 1 specifications as defined in the latest editions of ANSI/ASA S1.43 (ASA 2007) and ANSI/ASA S1.11 (ASA 2009). The instrumentation should use parallel octave-band filters (covering the nine frequency bands from 31.5 to 8000 Hz), where all frequency bands are processed simultaneously. The manufacturer's stated noise floor of the sound level meter should not be higher than 25 dB(A).

A handheld, Type 1, portable acoustic calibrator shall be used to check the instrumentation calibration before and after each measurement session. Both the meter (including the microphone) and the portable acoustic calibrator shall be certified to have been calibrated by an independent testing agency that is traceable to National Institute of Standards and Technology (NIST). The calibration date for the measurement system shall not be more than one year prior to the test date.

ADVANCED DATA COLLECTION EXAMPLES

Example worksheet is from Acoustics Worksheets-Forms Examples.xlsx. This is the Advanced Data Collection Worksheet.

An example of an Advanced Data Collection worksheet is included in FIgure J-7 and a blank worksheet is provided in the Diagnostic+Advanced Level Acoustics Workbook on the companion CD. A separate sheet is required for each room or sound-sensitive space, and each sheet provides space for plan details of the room dimensions and finishes. The consultant records site details on the sheet that

Figure J-6 Integrating Sound Level Meter with Parallel Octave Band Filters
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Figure J-7 Example Acoustics Data Collection Worksheet

will be useful in the diagnostic and analysis of the acoustic issue. Room sound pressure levels (L_{eq} in dB(A)) are typically measured and plotted against the NC values. Acoustic measurements and criteria can vary significantly with the building's use.

If room use requires good speech communication, the reverberation time (T_{60}) should also be measured using the impulsive excitation method (Schroeder method) or, alternatively, using the interrupted noise method in accordance with ASTM E 2235 (ASTM 2012). The impulsive excitation method requires a Type 1 sound level meter equipped with internal reverberation analysis software plus an impulsive source, which can be a large balloon or a starter's pistol. The interrupted noise method requires a sound level meter equipped with reverberation analysis software, a noise generator (which is typically internal to the meter), and a full-range powered loudspeaker, all under the control of the sound level meter. The reverberation times shall be calculated in octave or 1/3-octave bands from 100 to 4000 Hz. One possible test setup is illustrated in Figure J-8.

Instrumentation meeting the above requirements will range in cost from \$9000 to \$12000, including a powered loudspeaker. Periodic measurements are

Figure J-8 Measurement of Room Reverberation Time Using Interrupted Sound Source and Sound Level Meter
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not required unless the subsequent occupant survey or walk-through observations suggest that the acoustic environment has changed from the initial assessment.

Definitions and Acronyms

ACRONYMS

ADPI	air diffusion performance index
AHU	air-handling unit
ANSI	American National Standards Institute
ASTM	ASTM International
BAS	building automation system
BEM	building energy model
BOMA	Building Owners and Managers Association International
Btu	British thermal units
BUS	Building Use Studies
CAD	computer-aided design
CBE	Center for the Built Environment
CBECS	Commercial Building Energy Consumption Survey
CFD	computational fluid dynamics
cfm	cubic feet per minute
CFR	Current Facility Requirements
CIBSE	The Chartered Institution of Building Services Engineers
CO_2	carbon dioxide
CoC	contaminants of concern
CRI	Color Rendering Index
Cx	commissioning
CxA	commissioning authority
dB	decibel
dB(A)	A-weighted sound level in decibels
DX	direct expansion
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
EBCx	existing building commissioning
ECI	energy cost index
ECRM	energy cost reduction measure
EEM	energy efficiency measure
EIA	Energy Information Administration
EMCS	energy management and control system
EPA	U.S. Environmental Protection Agency

ERU	energy recovery unit
EUI	energy use index
FFT	
FTE	full-time equivalent
gpd	gallons per day
hp	horsepower
Hz	hertz
IAQ	indoor air quality
IEQ	indoor environmental quality
IES	Illuminating Engineering Society of North America
IP	Internet Protocol
L_{eq}	equivalent sound level
M&V	measurement and verification
MCS	multiple chemical sensitivity
MERV	Minimum Efficiency Reporting Value
NC	noise criteria
NIST	National Institute of Standards and Technology
NWS	National Weather Service
O&M	operation and maintenance
OA	outdoor air
OAT	outdoor air temperature
OPR	Owner's Project Requirements
OSHA	Occupational Safety and Health Administration
PEC	personal environmental control
PMV	Predicted Mean Vote
ppmw	parts per million by weight
PRTU	packaged rooftop unit
RH	relative humidity
SBS	sick building syndrome
T_{60}	reverberation time
TAB	test and balance
TAC	task-ambient conditioning
USGBC	U.S. Green Building Council
VAV	variable air volume
VDT	visual display terminal
VFD	variable-frequency drive
VOC	volatile organic compound
WSHP	water-source heat pump

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