ASME EA-3G–2010

(ANSI Designation: ASME TR EA-3G–2010)

# Guidance for ASME EA-3, Energy Assessment for Steam Systems



AN ASME TECHNICAL REPORT

SETTING THE STANDARD

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# Guidance for ASME EA-3, Energy Assessment for Steam Systems



A TECHNICAL REPORT PREPARED BY ASME AND REGISTERED WITH ANSI

ASME
SETTING THE STANDARD

Three Park Avenue • New York, NY • 10016 USA

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This Guide will be revised when the Society approves the issuance of a new edition. There will be no addenda or written interpretations of the requirements of this Guide issued to this edition.





The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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# FOREWORD

This guidance document provides technical background and application details in support of the understanding and application of ASME EA-3, Energy Assessment for Steam Systems. This guidance document provides background and supporting information to assist in applying the standard. The guidance document covers such topics as the rationale for the technical requirements of the assessment standard; technical guidance, application notes, alternative approaches, tips, techniques, rules-of-thumb; and example results from fulfilling the requirements of the assessment standard. This guidance document was developed to be used as an application guide on how to utilize ASME EA-3.

ASME EA-3 provides a standardized framework for conducting an assessment of steam systems. A steam system is defined as a system containing steam generator(s) or other steam source(s), a steam distribution network, and end-use equipment. Cogeneration and power generation components may also be elements of the system. If steam condensate is collected and returned, the condensate return subsystem is a part of the steam system. Assessments performed using the requirements set by ASME EA-3 involve collecting and analyzing system design, operation, energy use, and performance data, and identifying energy performance improvement opportunities for system optimization. These assessments may also include additional information, such as recommendations for improving resource utilization, reducing per unit production cost, reducing life cycle costs, and improving environmental performance of the assessed system(s).

ASME EA-3 provides a common definition for what constitutes an assessment for both users and providers of assessment services. The objective is to provide clarity for these types of services that have been variously described as energy assessments, energy audits, energy surveys, and energy studies. In all cases, systems (energy-using logical groups of industrial equipment organized to perform a specific function) are analyzed through various techniques resulting in the identification, documentation, and prioritization of performance improvement opportunities.

This Guide is part of a portfolio of documents and other efforts designed to improve the energy efficiency of industrial facilities. Initially, assessment standards and guidance documents are being developed for compressed air, process heating, pumping, and steam systems. Other related existing and planned efforts to improve the efficiency of industrial facilities include

*(a)* ASME Assessment Standards, which set the requirements for conducting and reporting the results of compressed air, process heating, pumping, and steam assessments

*(b)* a certification program for each ASME assessment standard that recognizes certified practitioners as individuals who have demonstrated, via a professional qualifying exam, that they have the necessary knowledge and skills to apply the assessment standard properly

*(c)* an energy management standard, A Management System for Energy, ANSI/MSE 2000:2008, which is a standardized approach to managing energy supply, demand, reliability, purchase, storage, use, and disposal and is used to control and reduce an organization's energy costs and energy-related environmental impact

NOTE: ANSI/MSE 2000:2008 will eventually be superseded by ISO 50001, which is now under development.

*(d)* an ANSI measurement and verification protocol that includes methodologies for verifying the results of energy efficiency projects

*(e)* a program, Superior Energy Performance, that will offer an ANSI-accredited certification for energy efficiency through application of ANSI/MSE 2000:2008 and documentation of a specified improvement in energy performance using the ANSI measurement and verification protocol

The complementary documents described above, when used together, will assist organizations seeking to establish and implement company-wide or site-wide energy plans.

Publication of this Technical Report that has been registered with ANSI has been approved by ASME. This document is registered as a Technical Report according to the Procedures for the Registration of Technical Reports with ANSI. This document is not an American National Standard and the material contained herein is not normative in nature. Comments on the content of this document should be sent to the Managing Director, Technical, Codes and Standards, ASME.

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**General.** ASME documents are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this technical report may interact with the Committee by proposing revisions and attending Committee meetings. Correspondence should be addressed to:

Secretary, EA Committee
The American Society of Mechanical Engineers
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New York, NY 10016-5990
http://go.asme.org/Inquiry

**Proposing Revisions.** Revisions are made periodically to the technical report to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the technical report. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this technical report. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

**Attending Committee Meetings.** The EA Committee holds meetings or telephone conferences, which are open to the public. Persons wishing to attend any meeting or telephone conference should contact the Secretary of the EA Standards Committee.

# GUIDANCE FOR ASME EA-3, ENERGY ASSESSMENT FOR STEAM SYSTEMS



## 1 SCOPE

### 1.1 Scope

This guidance document provides an application guide on how to utilize ASME EA-3, Energy Assessment for Steam Systems. This guidance document provides background and supporting information to assist in applying the standard.

### 1.2 Purpose

ASME EA-3 sets the requirements that need to be performed during the assessment. ASME EA-3 was written in a form suitable for a standard, with concise text and without examples or explanations. This document was developed to be used in conjunction with the standard to give basic guidance on how to fulfill the requirements of the standard. This document is only a guide, it does not set any new requirements, and ASME EA-3 can be used with or without this document.

## 2 DEFINITIONS

*assessment:* activities undertaken to identify energy performance improvement opportunities in a steam system that consider all components and functions, from energy inputs to the work performed as the result of these inputs. Individual components or subsystems need not be addressed with equal weight, but assessments shall be sufficiently comprehensive to identify the major energy efficiency opportunities for improving overall system energy performance. System impact versus individual component characteristics should be discussed.

*assessment conditions:* the operating conditions during the assessment period that serve as the basis of the measurements for the assessment investigations.

*baseline conditions:* a set of operating conditions, and the associated system energy use, that the assessment team will use as a basis for calculating energy improvement opportunity impacts. Baseline conditions can, for example, be the assessment operating conditions, normal operating conditions, future operating conditions, or past operating conditions.

*Conservation of Energy (energy balance):* the application of the principle of *conservation of energy* as developed from the *first law of thermodynamics* is identified as an *energy balance*. Stated simply, the principle of conservation of energy is as follows: *energy can neither be created nor destroyed by natural processes; it can only change form*. An energy balance can be applied to a single component, a composite subsystem, or an entire system.

*Conservation of Mass (mass balance)*: the application of the principle of *conservation of mass* as developed from the *first law of thermodynamics* is identified as a *mass balance*. Stated simply, the principle of conservation of mass is as follows: *mass can neither be created nor destroyed by natural processes; it can only change form*. A mass balance can be applied to a single component, a composite subsystem, or an entire system.

*efficiency:* the general term used to describe the effectiveness of energy utilization in a component, a subsystem, or an entire system. Specific definitions are ascribed to the various applications of efficiency. A general identification of efficiency that satisfies most applications is the ratio of the useful energy output divided by the energy input.

*energy stream:* a flow of material, heat, and/or power crossing a boundary of a system. Common energy streams are electricity, fuel (e.g., natural gas, coal, process waste fuel), stack gas, steam, or water (including blowdown and condensate).

*field measurement:* the evaluation of a system variable through the use of instrumentation. Typical field measurements include temperature, pressure, and flow.

*First Law of Thermodynamics:* the combined amount of mass and energy is neither created nor destroyed by natural processes; it can only change form. In other words, the amount of mass and energy in the universe remains constant. In steam system applications it is almost always appropriate to separate the First Law of Thermodynamics into the principle of the *Conservation of Mass* and the principle of the *Conservation of Energy*.

*impact costs:* the true economic influence of a commodity. Impact costs are commonly expressed in terms of an applicable unit of energy ($\$/10^6$ Btu, for example) and accurately reflect the financial influence of a specific system operational or equipment change. The manner of calculation of impact cost may vary, depending on a specific action considered.

*model:* one or more equations expressing conservation principles and other relationships that describe the characteristics of an energy system. The equation(s) may be solved manually (if sufficiently simple) or with computer simulation (computer model).

*normal operating conditions:* a set of operating conditions when the equipment loading, system parameters, and process demands are reflective of typical or nominal conditions.

*operating conditions:* those of a facility are the basic system characteristics, such as steam production, equipment loading, process demands, and many additional parameters. These conditions are both qualitative (e.g., type of boiler controls) and quantitative (e.g., boiler steam production level).

*steam system:* a system containing steam generator(s) or other steam source(s), a steam distribution network, and end-use equipment. Cogeneration and power generation components may also be elements of the system (e.g., gas turbines, backpressure steam turbines, condensing steam turbines). If steam condensate is collected and returned, the condensate return subsystem is a part of the steam system.

*utility:* identified as any energy commodity. This includes purchased electricity, onsite generated electricity, fuels, steam, compressed air, and all other energy resource commodities supplied to the system.

## 3 OVERVIEW OF THE STANDARD — HOW TO USE ASME EA-3

ASME EA-3 is organized in sections, as described in paras. 3.1 through 3.7.

### 3.1 Section 1: Scope and Introduction

This section includes the scope for the standard, limitations of the standard, and an introduction on how to use the standard that includes information on the systems approach and the system engineering process. No guidance is provided for this section of the standard.

### 3.2 Section 2: Definitions

This section includes definitions of terms used in the standard. No guidance is provided for this section, and these definitions are repeated in section 2 of this document.

### 3.3 Section 3: References

This section includes documents that are referenced in the standard. No guidance is provided for this section of the standard.

### 3.4 Section 4: Organizing the Assessment

This section includes requirements on how to organize an assessment including identification of team members and responsibilities, requirements for preliminary data collection and analysis, and requirements on the development of assessment goals and a plan of action. Guidance is provided in section 4 of this document.

### 3.5 Section 5: Conducting the Assessment

This section includes requirements on how to conduct an assessment (the implementation phase of the plan of action). Guidance is provided in section 5 of this document.

### 3.6 Section 6: Analysis of Data From the Assessment

This section includes requirements on how to analyze the data collected during an assessment, including the development of a baseline profile. Guidance is provided in section 6 of this document.

### 3.7 Section 7: Reporting and Documentation

This section includes requirements on how to structure the assessment report. Guidance is provided in section 7 of this document.

## 4 GUIDE TO ORGANIZING THE ASSESSMENT

Conducting a steam system assessment should be considered a project, and as such, should be guided by commonly used steps in good project management. The steam system assessment process (project) will require the clarification of objectives (including the identification of all deliverables), the assignment of personnel responsibility, the establishment of a work schedule and deadlines, the establishment of a budget and procurement of funding, and the specification of reporting required. These good project management steps are embodied in the actions described below.

### 4.1 Identification of Assessment Team Members

Primary factors required for the success of a steam system assessment are the identification of key personnel, the establishment of management commitment, and the establishment of dependable lines of communications among all personnel authorizing and participating in the assessment. In preparing for the assessment, the following activities should be undertaken to identify critical personnel.

**4.1.1 Required Functions and Personnel.** Potential assessment team members to fill the functional roles identified in the standard and other issues related to personnel are discussed below.

(a) *Authorized Manager*. The authorized manager accepts overall responsibility and has final decision-making authority. Responsibilities include allocating resources necessary to plan and execute the assessment. Resources include items such as funding, availability of personnel, and requisitioning internal work orders and supplies. The authorized manager allocates and authorizes the participation of outside contractors and consultants and facilitates the participation of any necessary outside personnel requiring contracts, scheduling, confidentiality agreements, and statements of work. The essential level of support can be reflected in a letter, memorandum of understanding, e-mail message(s), or verbally in a direct conversation. The authorized manager participates in follow-up consideration of the proposed energy saving projects recommended.

(b) *Assessment Team Leader*. The assessment team leader guides the team through the assessment process. The team leader is responsible for all aspects of the assessment directly or through delegation. The team leader can be an onsite representative, an offsite employee of the facility, or an external resource.

Initially the team leader should organize the assessment team and identify the methods to coordinate the assessment. The total number of assessment team members needed for a successful outcome generally reflects the size and extent of the steam system to be assessed. Additionally, the knowledge level of individual team members should be a determining factor in the assessment team formation process. Assessment team members can be involved in every aspect of the assessment or can participate in the assessment of specific target areas.

Interviewing key plant personnel is an essential investigation tool in the assessment process. Typically operations personnel, maintenance personnel, and area managers embody the bulk of the knowledge base in assessment target areas. It is essential to include this knowledge base in the assessment process. Often individuals develop a significant knowledge base in a specific area of the steam system, qualifying them as subsystem specialists. Subsystem specialists should be included in the assessment process. If the facility has a designated projects improvement leader, this individual should participate in team meetings.

(c) *Steam System Expert*. The team should include a steam system expert. This individual, either a corporate or plant employee or an outside consultant, should have the requisite qualifications, background, experience, and recognized abilities to perform the assessment activities, data analysis, and report preparation.

A steam system expert is an individual who has knowledge of different types of steam systems used by the industry, and the design and operation of the various components that go into a steam system. An example (but not a necessity) of such qualification is a certification under the U.S. Department of Energy's steam system qualified specialist training or similar training offered by other organizations or institutions. If interested, the user of this guidance document may refer to The U.S. Department of Energy Industrial Technologies Program Web site (as of April 2010), www.eere.energy.gov/industry, to get further information on steam system qualified specialist training.

*(d) Engaging the Plant or Facility Manager*. Engagement of the plant or facility manager is of prime importance to the success of a steam assessment. The manager must realize value in the assessment ("buy-in") to authorize the allocation of employee time, money, and other resources. The manager should be contacted directly by the assessment team to solicit approval and support. The expected practical results of the assessment should be explained, and questions about the assessment process should be addressed. The expected duration of the assessment and timing of assessment events should be addressed along with the anticipated personnel time commitments. An assessment budget should be prepared and presented for approval. The manager should be invited to the initial and final (exit) meetings to ensure first-hand engagement in the assessment process and to impart knowledge of the assessment process and the specific results to be obtained.

*(e) Establishment of Effective Interactions With Assessment Team and Other Site Personnel.* A steam system assessment by its nature requires the transfer of technical and related information between plant employees and the assessment team. Thus, it is imperative to establish effective lines of communication by a variety of means including personal meetings, phone, or e-mail. The assessment team should contact all important parties, establish communication lines by sharing points-of-contact, days and hours of availability, and clarify roles and expectations. Ideally, all personnel involved in the assessment process will attend the initial meeting to establish personal relationships needed for effective execution of the assessment process. This group includes those active in the assessment discovery process, operations personnel, maintenance personnel, and site management.

*(f) Identification of Specialists.* Steam system assessments require evaluation of the operating characteristics of the system with respect to the practical improvement limits of the equipment. Therefore, a combination of skills is required to complete the steam system performance evaluation. The appropriate skills combination includes operational knowledge, equipment limitation data, and evaluation methodologies. The assessment team must contain the technical knowledge associated with these areas. Very often multiple team members are required to assemble this knowledge base. It is a principal task for the assessment team to bring the appropriate specialists to the team and to identify plant specialists as follows. An appropriately selected team member (plant employee or outside professional) should be able to select individuals who have the requisite knowledge to assess the plant's steam system. Thus, with the approval and support of the manager, the assessment team will invite team participation of selected specialists. It will be required that the combination of individuals with a collective knowledge of all parts of the steam system be employed in the assessment process. It is the responsibility of the assessment team to judge that sufficient expertise is available to conduct the assessment. In the case that knowledge is lacking in one or more subject areas, the importance of the assessment area must be evaluated to determine if additional specialists must be involved in the assessment.

*(g) Clarification of the Roles of Specialists in the Assessment*. The primary role of every identified facility specialist is to provide detailed technical information to those member(s) of the assessment team who will perform assessment analysis. It is important for the assessment team to schedule the availability of each identified, essential specialist for interviews, for assistance in the collection of data, and performance of measurements or for changes in process operations needed to quantify energy performance. The specific roles of each identified specialist should be clarified through direct contact with the assessment team during the assessment preparation period, prior to the initial meeting.

*(h) Selection of Team Members.* It is important for a steam system assessment team to comprise a sufficient number of knowledgeable professionals to achieve a successful assessment outcome. Outside experts and/or internal facility employees may be selected to serve as team members. In consultation with facility managers, the assessment team must initially identify specific steam system or heated equipment focus areas for the assessment. With the focus areas identified, the assessment team in consultation with facility managers should identify a set of outside and/or internal individuals as prospective team members. These prospective team members should then be contacted to ensure their experience level (if not known) and their availability and interest in serving on the assessment team.

*(i) Clarification of the Roles of Team Members.* A steam system assessment requires several series and parallel tasks to be performed by assessment team members and plant personnel. To ensure the best outcome, the component tasks should be performed by the team member(s) and plant personnel most knowledgeable in relevant subject areas. For example, if boiler stack gas analysis is to be performed, it should be done by a team member working with plant personnel experienced in making such measurements. Role assignment also presents the opportunity to conduct the assessment in a time efficient manner by having each team member work on subject area(s) and activities most familiar to him/her. The choice of roles for each team member should be discussed and decided in the early planning stages for the assessment. Reasonable changes in roles can be made in response to unforeseen circumstances that may develop as the assessment proceeds. The specific roles undertaken by the team members should be documented as a part of the assessment record.

*(j) Plant Project Improvements.* Some facilities may require that new projects (including energy improvement projects) be approved by a designated internal individual. Since it will be desirable for recommended improvement

measures to be approved for implementation, this individual should be identified at the beginning of the assessment and be included as a member of the assessment team. If the facility does not operate with a person in this position, then this step is not required.

*(k) Identification of Key Area Managers/Operators.* The performance of a steam assessment will require that the assessment team interact with several plant employees to obtain essential steam system information, to be shown and given access to relevant areas of the facility, and to assist in the performance of required measurements. It is of essential importance for the assessment team to interact with the most knowledgeable facility individuals for the indicated purposes. In the planning stages of the assessment, the assessment team should meet with the manager and his/her line managers to identify the most appropriate, knowledgeable individuals to serve as key area managers and operators. The number of individuals selected will depend on the focus of the assessment and the extent to which steam is used in multiple facility processes.

## 4.2 Facility Management Support

Completing an assessment in a large and complex facility can overextend resources. As a result, it may be appropriate to divide the assessment of a large facility into subsystems, with each subsystem being composed of a complete steam system. As an example, a facility equipped with many production units and multiple steam-power generation facilities could choose to complete an assessment on one steam-power generation facility and a selection of production units. Significant care must be given to the integration of all the units within the overall system.

Alternately, a staged assessment approach can be taken, which will address each area of the steam system during distinct assessment events. As an example, boiler efficiency and performance can be addressed in one event. Cogeneration activities can be assessed at a later date followed by the remaining steam system areas. In this approach the steam system assessment will be complete after all of the individual assessments are complete and the interactions are evaluated.

It is imperative to note that an appropriate steam system assessment must utilize a "systems approach." Because each component in a steam system impacts other components and the system as a whole, component interactions must be considered (system equipment does not operate in isolation). A complete and thorough steam assessment includes investigations into all aspects of the steam system — boiler efficiency, cogeneration (combined heat and power) applications, primary energy resource selection, steam end-use utilization, heat recovery, condensate recovery, steam traps, insulation, and other fundamental areas. These evaluations must incorporate interactions with other equipment and the impact on the system as a whole. Each target area is filled with many investigation paths and vital evaluations. These interaction complexities result in the necessity of utilizing system models for many of the assessment evaluations.

## 4.3 Communications

The assessment team should have access to all steam system equipment for observing normal operations and making needed measurements. During assessment planning, the areas of the facility where steam system components are located and need to be inspected should be identified. The need for the availability of specific personnel to provide access should be identified and schedules should be set for visits to plant areas.

Since access to plant areas and data is needed to complete a steam assessment, issues of the confidentiality of plant technology and equipment must be addressed in the planning of assessment activities. Team members should be prepared to execute confidentiality agreements as a part of receiving facility information and gaining access to steam system areas.

Issues related to physical safety for plant visits should be clarified in assessment planning. The need for safety equipment and safety training must be identified and scheduled preferably prior to but no later than the first day of onsite assessment activities.

The requirement for general and professional liability insurance covering assessment team members performing a steam system assessment in the facility must be clarified and arrangements must be made to satisfy such insurance requirements. The possibility of waiving the normal insurance requirements for selected assessment team members can be discussed. It is recommended that all outside team members have adequate health and accident insurance coverage as a minimal requirement for service on the assessment team.

## 4.4 Access to Equipment, Resources, and Information

To ensure a complete and thorough process, it is essential that assessments be scheduled for periods when normal facility operations are occurring, and not during start-ups or during periods of scheduled or unplanned downtime. In some facilities abnormal operating conditions significantly impact operations and facility costs. These conditions should not be ignored — it may be necessary to target these conditions for evaluation purposes. However, it should be noted that, in general, normal facility operations are the primary focus of evaluations and assessment.

For the performance of a complete and comprehensive assessment of a plant or facility steam system, it is necessary to physically inspect and make selected measurements on the system components. Plant or facility personnel generally have access to all areas. Appropriately safety-trained personnel from outside the assessment team OR personnel not a part of the assessment team wearing safety equipment should have access to specific plant or facility areas. When necessary, an escort should accompany assessment team members when they move about the plant or facility. In areas posing substantial physical risk, appropriately trained facility employees should collect data for the assessment team.

### 4.5 Initial Data Collection and Evaluation

As specified in the steam assessment standard (ASME EA-3), several items of preliminary information should be obtained and reviewed by the assessment team before initiation of the onsite assessment. The areas needing particular attention are listed below. For the assessment team to understand all aspects of facility operation affecting energy use, the following subjects should be discussed and clarified in terms of effects on steam system energy use:

*(a)* general system information (equipment overview, fuels used)
*(b)* steam system operating schedule
*(c)* operational information
*(d)* production issues (e.g., bottlenecks) affecting steam use
*(e)* recent history of significant changes to or upgrades to steam system
*(f)* existing heat and mass balances
*(g)* past steam energy assessments and improvement opportunity reports

**4.5.1 Initial Facility Specialist Interviews.** There is no additional guidance for this clause.

**4.5.2 Primary Energy Cost.** To characterize the full economic cost of steam production, and the economic results from implementing one or more energy-reduction measures, the following factors must be considered:

*(a)* the types of different fuels that can be used in the boiler(s) and their physical/thermodynamic properties
*(b)* the current and projected future unit costs of these fuels
*(c)* the time trends in boiler energy use and cost
*(d)* the process uses of steam that affect boiler fuel use
*(e)* the environmental impacts and related cost effects of the use of different boiler fuels
*(f)* the identification of "impact fuels" appropriate to the minimization of boiler energy use and fuel cost

Boilers commonly utilize one or more of the following fuels: coal, fuel oil, natural gas, wood, or process wastes such as fuel gas from chemical processing or black liquor from paper processing. For solid fuels, moisture content affects ease of combustion and energy value. Environmental emissions are points of concern for all fuels. Fuels containing sulfur can present significant issues.

Fuels should be analyzed to determine composition and heating value. Heating values are specified in units of energy per unit mass (or volume) and are reported as higher or lower heating values. The higher heating value includes the recovered heat of condensation from the combustion water vapor, whereas this is excluded for lower heating value. It should be noted that boiler efficiency in the U.S. is normally specified in terms of the fuel higher heating value.

Fuels are purchased on a mass basis (solid fuels), a volume basis (liquid and gaseous fuels), or energy basis. Purchase price may be via long-term contracts or on a current market cost basis. Rate schedule(s) and copies of monthly (or other billing period) bills must be examined to determine current fuel costs. Trends in boiler energy use should be analyzed for periods sufficient to reflect seasonal and production cycle variations in steam generation rate. Although it is common to collect and analyze 1 yr of energy bills for each utilized fuel (including electricity), longer periods may need to be investigated in the case of unusual circumstances. Fuel costs used in analysis should be based on current or projected — not past — historical cost. Fuel price volatility should also be considered in establishing the unit costs used in the evaluations.

**4.5.3 Impact Fuels.** For the analysis of energy-saving projects, one or more "impact fuels" must first be determined. An "impact fuel" is the one whose use would be reduced (or increased) preferentially (among other usable fuels) when steam production is reduced (or increased). Many factors affect the choice of the impact fuel, including

*(a)* fuel unit cost
*(b)* boiler individual fuel consumption capacity
*(c)* provisions for storage and handling of solid and liquid fuels

*(d)* environmental emissions constrained by current or new emissions
*(e)* operational reasons for the use of specific fuel(s)
*(f)* relative combustion efficiency (based on composition)

For electricity use, it is common for rate schedules to include (among other costs) commodity (kilowatt-hour) and peak demand (kilowatt) charges. Thus, if a project results in a reduction in electricity use, the value of the commodity saved must be evaluated for the "correct bracket" of the rate schedule. Electricity commodity savings may or may not impact demand savings depending on whether the action under consideration reduces demand on a continual, long-term basis or not. Facilities with cogeneration systems must be analyzed to determine the effective cost of electricity and thermal energy (including steam) produced.

For all boiler fuel use, environmental emission regulations must be considered if an alternative fuel is recommended on a cost basis. The modification of boiler combustion process (e.g., different fuel, modified burner) should receive appropriate attention during the assessment. Often facilities are reluctant to take action requiring a new or modified emissions permit due to uncertainty of approval and new risks of exceeding emissions limits.



## 4.6 Assessment Goals and Scope

There is no additional guidance for this clause.

## 4.7 Assessment Plan of Action

**4.7.1 Identification of Other Assessment Team Members Required.** The dates and times for the assessment team to meet with key plant or facility managers and process operators should be specified and agreed upon by all individuals who will be participating in each meeting event. Schedules should be flexible allowing modification during the course of the assessment. It should be recognized that all data initially identified as essential to the assessment should be obtained in discussions with knowledgeable facility staff. If an initially scheduled person becomes unavailable during the period of the assessment, a suitable substitute person should be identified, or the initially scheduled interview should be rescheduled. See para. 4.1.1 for additional information on other assessment team members.

### 4.7.2 Assessment Scheduling

*(a) Assessment Activity Scheduling.* Since several facility employees will need to interact with the assessment team at different times, it is essential to schedule the dates for the assessment. The schedule should include daily events such as key meetings and interviews. Notice of planned assessment meetings and events should be transmitted to all relevant parties by direct communication, electronic mail, telephone, or other suitable means for group communication.

*(b) Initial Meeting.* An initial meeting should include the assessment team and plant or facility managers, and other interested parties. At this meeting, the nature of the assessment, including its focus and objectives, personnel involved, steps and procedures to be carried out, and the plan for an exit meeting should be agreed upon. The final resolution of any conflicts relative to personnel availability and meeting schedules should be completed at the initial meeting.

*(c) Interim Meetings.* Periodic reporting to facility managers in the form of debriefings should occur as agreed upon by the assessment team. Also, irregularities may occur during an assessment (e.g., the failure of a computerized records system). If and when such events occur, the assessment team needs to determine a corrective course of action.

## 4.8 Goal Check

There is no additional guidance for this clause.

# 5 GUIDE TO CONDUCTING THE ASSESSMENT

## 5.1 Overall Assessment Method

*(a) General Methodology.* Every complete steam system assessment will target the entire steam system (generation, distribution, end-use, and recovery). The goal of the evaluation process is to establish the path forward for each aspect of the steam system. The possible ranges of the path forward are very broad. One end of the range would be to maintain the current operating conditions, because the system components in question are being operated in an excellent manner and there is minimal incentive to modify operations. Another point within the range could be to adjust control set points to improve operational characteristics. The other end of the range could be to replace or add

equipment because of desired improvements. The assessment evaluation targets and investigations are designed to identify an appropriate path forward.

*(1) Targets of Steam System Assessment.* The investigation must be approached from a systems perspective; that is to say, each component will be evaluated with respect to its impact on the entire steam system. The primary targets of the steam system assessment are, but not limited to

*(a)* boiler operations
*(b)* combustion turbine operations
*(c)* primary energy resource selection (fuel and power)
*(d)* steam turbine operations
*(e)* steam end-use utilization
*(f)* thermal insulation
*(g)* condensate recovery
*(h)* steam trap management
*(i)* heat recovery

*(2) Incentives for Modifications.* Incentive to modify or change steam system operations can be derived from many avenues. Most, if not all, incentives are directly connected to economic components. A primary task of the assessment team is to translate operational changes into economic impacts. Some of the common incentives for modifications to the steam system are provided in the following list (not prioritized):

*(a)* energy impact
*(b)* environmental impact
*(c)* maintenance impact
*(d)* site reliability
*(e)* site safety
*(f)* site productivity or quality improvement
*(g)* alignment with long-term strategies

Again, the methodology used for steam system assessments should involve investigation of every aspect of the steam system. In a comprehensive examination every area is targeted, and an expert evaluation including a path forward is prescribed. As an example, for a given assessment, an evaluation may indicate that the thermal insulation throughout the facility is in excellent condition. The insulation evaluation was completed from specific measurements and observations, such as surface temperature measurements, visual inspection of components, and design specifications for insulation projects. In this instance (insulation evaluated to be in excellent condition) the path forward for thermal insulation would be to continue the current strategy of inspecting and installing proper insulation and maintaining the insulation to excellent standards.

As another example, investigation in the boiler operations arena may indicate that the measured boiler efficiency is relatively low for the type of equipment in place and the fuel burned in the boiler. This would further indicate that additional measurements are required to determine what improvement opportunities exist. Additional measurements, like combustion zone oxygen content, could indicate significant deviation from the optimal values attainable by the equipment. For the example of combustion zone oxygen content being elevated, the path forward would be to investigate the potential of reducing the excess combustion air. If the boiler is equipped with a simple position-related oxygen management system, the assessment team may undertake an effort to tune the boiler utilizing appropriate evaluation instruments. If improvements are attained, the assessment team should evaluate the energy impact associated with the modification as well as the economic impact. The path forward for this specific example would then be to proceed with an evaluation of upgrading the combustion controls of the boiler to achieve improved and more consistent combustion management system. The evaluations would continue in light of the potential improvement, the capability of the equipment, and the required economic investment.

Each area of the steam system will be investigated to determine the potential for improvement. When evaluations indicate improvements can be attained, then all potential solutions should be evaluated to determine the most appropriate strategy.

Every evaluation must consider the broader system impacts associated with the potential opportunity. As an example, a common energy recovery activity is to recover thermal energy from the boiler blowdown. However, if the system being evaluated is equipped with a large amount of thermal energy recovery from the process units, then recovering blowdown thermal energy may simply result in reduced process energy recovery. This is obviously a simplified example, but it is intended to emphasize the importance of completing the assessment with a systems approach. Most often the interrelations experienced in complex steam systems require computer modeling to aid in the evaluation process.

Each facility will be different with respect to the opportunities and their prescribed treatments. However, the fundamental investigation methods are identical, and the major points of investigation never change. In other words, boilers will be investigated using traditional boiler efficiency evaluations, steam turbines will be evaluated with isentropic efficiency studies, condensate recovery will be evaluated based on temperature and flow characteristics, and all of the other classic target areas will be addressed with classic evaluation methods.

The type of assessment approach described here evaluates the general operating conditions of all of the system areas. This evaluation is used to identify areas that require further and more detailed investigation. The assessment team is continually evaluating the need for and the potential benefit associated with more detailed investigation of each target area and its potential impact on the system as a whole.

**5.1.1 Mass and Energy Balancing.** Steam system assessments are, by their very nature, events that investigate and analyze individual components, groups of components, and composite systems. The fundamental tools required for all of these investigations are the bedrock principles of physics primarily focused on thermodynamics. Investigations attempted without these tools are less effective and more error prone. Quantification of steam production, distribution, end use, and recovery, both before and following energy reduction project implementation, requires the use of a set of equations expressing the principles of mass and energy conservation.

*(a)* During a steam system assessment, mass and energy balancing are used to

*(1)* determine changes in operating characteristics associated with component modifications
*(2)* evaluate the system impact of component modifications
*(3)* determine boiler efficiency indirectly from the individual boiler losses
*(4)* determine turbine efficiency from shaft power and steam flow
*(5)* characterize the end use of steam (mass and energy)
*(6)* verify the accuracy of direct measurements and/or for the estimation of an unknown (practically unmeasurable) quantity when other quantities in the balance equation are known or measureable

For each mass and/or energy balance performed, it must be determined whether a steady-state or unsteady-state analysis is needed. For significant time-varying conditions (e.g., changing boiler load) an unsteady-state analysis may be needed. Such analyses must include mathematical differential quantities, and the equation(s) to be solved are differential equations almost always requiring a computer solution. Fortunately, in most cases, it is adequate to use time-averaged quantities (or a bin type configuration) for a steady-state analysis that will yield algebraic equations.

The analysis of steam systems requires investigating the mass and energy flows through individual components as well as the overall utilization of materials throughout the system. The fundamental principle employed in these investigations is the *First Law of Thermodynamics*. The First Law of Thermodynamics, simply stated, is "the combined amount of mass and energy is neither created nor destroyed by natural processes. It can only change form." In other words, the amount of mass and energy in the universe remains constant. Additional fundamental principles are used in steam system evaluations, such as fluid flow, heat transfer, and the Second Law of Thermodynamics. However, the First Law of Thermodynamics is the primary tool. The Second Law of Thermodynamics is most often applied in steam system investigations when converting between thermal energy and power. The Second Law of Thermodynamics states that thermal energy cannot be converted completely into power. Additional important applications of the Second Law can be formulated, but energy conversion is the dominant application for steam system evaluations.

*(b) Application of the First Law of Thermodynamics.* In essentially all steam system evaluations it is appropriate to separate the First Law of Thermodynamics into two fundamental principles — the principle of Conservation of Mass and the principle of Conservation of Energy. These two evaluation tools are essential in analyzing steam systems. These principles are applied in many different manners with common arrangements listed as follows:

*(1)* a single mass flow stream (steam-condensate flow through a heat exchanger)
*(2)* multiple mass flow streams (deaerator steam and liquid entering and exiting flows)
*(3)* a single component (boiler) with multiple mass flows
*(4)* multiple components (boiler-steam turbine combination)
*(5)* the system as a whole

The normal convention used in applying these principles is to "draw a box around" the item being investigated. This "box" is identified as a "control volume" (cv). Once the control volume has been identified, the items that "cross the boundary of the control volume" are investigated. Items that can cross the steam system component boundaries are mass, work, and heat. The common representation of Conservation of Mass is provided in the following form:

$$\begin{bmatrix}\text{The rate of change of mass}\\ \text{contained in the control}\\ \text{volume with respect to time}\end{bmatrix} = \begin{bmatrix}\text{The sum of all mass}\\ \text{flow entering the control}\\ \text{volume at a given time}\end{bmatrix} - \begin{bmatrix}\text{The sum of all mass}\\ \text{flow exiting the control}\\ \text{volume at a given time}\end{bmatrix} \quad (1)$$

The common representation of Conservation of Energy is provided in the following form:

$$\begin{bmatrix}\text{The rate of change of energy}\\ \text{contained in the control}\\ \text{volume with respect to time}\end{bmatrix} = \begin{bmatrix}\text{The sum of all energy}\\ \text{flow entering the control}\\ \text{volume with heat at a given time}\end{bmatrix} + \begin{bmatrix}\text{The sum of all energy}\\ \text{flow entering the control}\\ \text{volume with mass at a given time}\end{bmatrix} - \begin{bmatrix}\text{The sum of all energy}\\ \text{flow exiting the control}\\ \text{volume with mass at a given time}\end{bmatrix} - \begin{bmatrix}\text{The sum of all energy}\\ \text{flow exiting the control}\\ \text{volume with work at a given time}\end{bmatrix} \quad (2)$$

Applying the principles of Conservation of Mass and Conservation of Energy to steam systems is often termed mass balance, energy balance, and mass-and-energy balance. The vast majority of mass-and-energy balances applied to steam systems assume steady-state, steady-flow conditions. This is a significant simplifying assumption dramatically decreasing the complexity of the solution. Steady-state, steady-flow indicates the operating parameters do not change with respect to time. In other words, the flow, pressure, temperature, work, heat transfer, and other parameters are constant with respect to time. For a steady-state, steady-flow system, if flow (for example) is measured at a point in time, then the measured flow rate at that point will remain constant for the complete evaluation period.

It is possible that the "real-world" component being investigated is not actually operating under steady-state, steady-flow conditions. Often average data is used to allow for implementing this assumption. The common representation of Conservation of Mass is provided in the following equation form. Steady-state, steady-flow assumptions are noted as SSSF.

$$\underbrace{\frac{dm_{cv}}{dt}}_{\text{SSSF}=0} = \sum_{\text{inlets}} \dot{m}_i - \sum_{\text{exits}} \dot{m}_e$$
$$\sum_{\text{inlets}} \dot{m}_i = \sum_{\text{exits}} \dot{m}_e \quad (3)$$

In other words, mass can flow into the control volume ($\sum_{\text{inlets}} \dot{m}_i$), mass can flow out of the control volume ($\sum_{\text{exits}} \dot{m}_e$), and mass can be stored in (depleted from) the control volume ($\frac{dm_{cv}}{dt}$); but it cannot be created or destroyed in the control volume. Of course, the steady-state, steady-flow (SSSF) assumption results in this storage term equaling zero. In other words, under steady-state, steady-flow, mass flow input equals mass flow output.

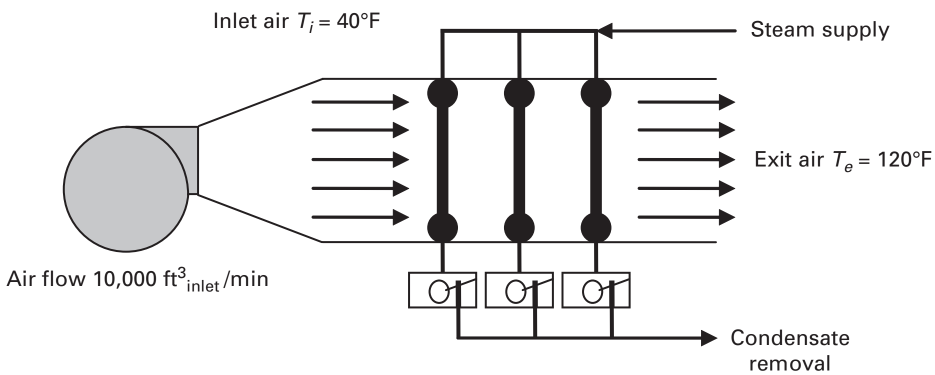
The idea that mass must be conserved produces the term "mass balance." Energy balance is provided by a similar description pertaining to energy. The common representation of Conservation of Energy is provided in the following equation form.

$$\underbrace{\frac{dE_{cv}}{dt}}_{\text{SSSF}=0} = \dot{Q}_{cv} + \sum_{\text{inlets}} \dot{m}_i \left( h_i + \frac{\vec{V}_i^2}{2} + g z_i \right) - \sum_{\text{exits}} \dot{m}_e \left( h_e + \frac{\vec{V}_e^2}{2} + g z_e \right) - \dot{W}_{cv}$$
$$\dot{Q}_{cv} + \sum_{\text{inlets}} \dot{m}_i \left( h_i + \frac{\vec{V}_i^2}{2} + g z_i \right) = \sum_{\text{exits}} \dot{m}_e \left( h_e + \frac{\vec{V}_e^2}{2} + g z_e \right) + \dot{W}_{cv} \quad (4)$$

Energy can enter the control volume in the form of heat transfer ($\dot{Q}_{cv}$) and mass flow ($\dot{m}_i$); energy can exit the control volume in the form of work ($\dot{W}_{cv}$) and mass flow ($\dot{m}_e$). In the representation provided in eq. (4), mass can carry four energy forms into (and out of) the control volume. The first form, potential energy ($g z_i$), is the energy associated with the elevation of the mass. The second form, kinetic energy ($\frac{\vec{V}_i^2}{2}$), is the energy associated with the velocity of the mass crossing the control volume boundary. The third form, internal energy of the flowing fluid, is the collective energy of the fluid molecules. The internal energy primarily resides in the translation, rotation, and vibration of the individual molecules. The fourth form, flow work, is the work associated with the pressure of the fluid as the mass crosses the boundary. Internal energy and flow work are combined into one thermodynamic property known as enthalpy ($h_i$).

These two principles form the basis for most steam system investigations. Figure 1 is provided to identify the general concepts associated with using the First Law of Thermodynamics. The example is a simple heat exchanger exchanging thermal energy between steam and air.

**Fig. 1 Heat Exchanger**






In the example system, 10,000 ft$^3_{\text{inlet}}$/min (±50 ft$^3_{\text{inlet}}$/min) of air is passing through a heat exchanger. Steam is used to raise the temperature of this air from 40°F to 120°F. The analysis assumes steady-state, steady-flow conditions. The analysis requires the components to be segregated with multiple control volumes.

The first control volume considers only the air passing through the heat exchanger. Therefore, air enters the control volume, air exits the control volume, and heat crosses the control volume boundary. For the air, Conservation of Mass can be written as follows:

$$\underbrace{\frac{dm_{cv}}{dt}}_{\text{SSSF}=0} = \sum_{\text{inlets}} \dot{m}_i - \sum_{\text{exits}} \dot{m}_e$$

$$\sum_{\text{inlets}} \dot{m}_i = \sum_{\text{exits}} \dot{m}_e \tag{5}$$

$$\dot{m}_i = \dot{m}_e = \dot{m}_{\text{air}}$$

The mass flow rate of air is the volume flow rate of air multiplied by the density of air. The volume flow rate was determined based on the inlet air conditions. These conditions result in the density of air being 0.0684 lbm/ft³. As a result, the mass flow rate of air entering and exiting the heat exchanger is calculated as follows:

$$\dot{m}_{\text{air}} = \rho \dot{V}_{\text{air}}$$

$$\dot{m}_{\text{air}} = 0.0684\,\tfrac{\text{lbm}}{\text{ft}^3}\left(10{,}000\,\tfrac{\text{ft}^3}{\text{m}}\right)\left(\tfrac{60\text{ min}}{1\text{ hr}}\right) \tag{6}$$

$$\dot{m}_{\text{air}} = 47{,}625\,\tfrac{\text{lbm}}{\text{hr}}$$

Conservation of Energy and Conservation of Mass can be simplified as shown below:

$$\underbrace{\frac{dE_{cv}}{dt}}_{\text{SSSF}=0} = \dot{Q}_{cv} + \sum_{\text{inlets}} \dot{m}_i\left(h_i + \frac{\vec{V}_i^2}{2} + gz_i\right) - \sum_{\text{exits}} \dot{m}_e\left(h_e + \frac{\vec{V}_e^2}{2} + gz_e\right) - \dot{W}_{cv}$$

$$\dot{Q}_{cv} = \dot{m}_e\left(h_e + \underbrace{\frac{\vec{V}_e^2}{2}}_{\substack{\text{negligible}\\\text{change}}} + \underbrace{gz_e}_{\substack{\text{negligible}\\\text{change}}}\right) - \dot{m}_i\left(h_i + \underbrace{\frac{\vec{V}_i^2}{2}}_{\substack{\text{negligible}\\\text{change}}} + \underbrace{gz_i}_{\substack{\text{negligible}\\\text{change}}}\right) \tag{7}$$

$$\dot{Q}_{air} = \dot{m}_{air}\left(h_e - h_i\right)$$

Thermo-physical property data for air at atmospheric pressure indicates the change in enthalpy of the air passing through the heat exchanger is 19.2 Btu/lbm. From this information the heating load is calculated as follows from eq. (7):

$$\dot{Q}_{air} = \dot{m}_{air}\left(h_e - h_i\right)$$

$$\dot{Q}_{air} = 47{,}625\,\tfrac{lbm}{hr}\left(19.2\,\tfrac{Btu}{lbm}\right) \tag{8}$$

$$\dot{Q}_{air} = 914{,}373\,\tfrac{Btu}{hr}$$

Conservation of Energy applied to the heat transfer surface between the air and the steam indicates the thermal energy added to the air is equal to the thermal energy lost from the steam. This is presented as follows:

$$\underbrace{\frac{dE_{cv}}{dt}}_{SSSF=0} = \overbrace{\dot{Q}_{cv}}^{\text{Heat transfer from steam and to air}} + \underbrace{\sum_{inlets}\dot{m}_i\left(h_i + \frac{\vec{V}_i^2}{2} + gz_i\right)}_{\text{No mass crosses the heat exchange surface}=0} - \underbrace{\sum_{exits}\dot{m}_e\left(h_e + \frac{\vec{V}_e^2}{2} + gz_e\right)}_{\text{No mass crosses the heat exchange surface}=0} - \underbrace{\dot{W}_{cv}}_{\text{No work}=0} \tag{9}$$

$$\dot{Q}_{air} + \dot{Q}_{steam} = 0$$

$$\dot{Q}_{air} = -\dot{Q}_{steam}$$

Conservation of Mass and Conservation of Energy applied to the steam passing through the heat exchanger is represented in the following equations. The properties of steam are taken as 20 psig steam with a temperature of 420°F (superheated). The properties of the condensate exiting the heat exchanger are taken as saturated liquid condensate with a pressure of 20 psig.

$$\underbrace{\frac{dE_{cv}}{dt}}_{SSSF=0} = \dot{Q}_{cv} + \sum_{inlets}\dot{m}_i\left(h_i + \frac{\vec{V}_i^2}{2} + gz_i\right) - \sum_{exits}\dot{m}_e\left(h_e + \frac{\vec{V}_e^2}{2} + gz_e\right) - \dot{W}_{cv}$$

$$\dot{Q}_{cv} = \dot{m}_e\left(h_e + \underbrace{\frac{\vec{V}_e^2}{2}}_{\text{negligible change}} + \underbrace{gz_e}_{\text{negligible change}}\right) - \dot{m}_i\left(h_i + \underbrace{\frac{\vec{V}_i^2}{2}}_{\text{negligible change}} + \underbrace{gz_i}_{\text{negligible change}}\right) \tag{10}$$

$$\dot{Q}_{steam} = \dot{m}_{steam}\left(h_e - h_i\right)$$

$$-914{,}373\,\tfrac{Btu}{hr} = \dot{m}_{steam}\left(227.40\,\tfrac{Btu}{lbm} - 1{,}246.85\,\tfrac{Btu}{lbm}\right)$$

$$\dot{m}_{steam} = 897\,\tfrac{lbm}{hr}$$

This simple analysis is intended to demonstrate the basic concepts associated with mass-and-energy balances. This example is by no means exhaustive, nor does it represent a complex analysis. It merely illustrates the basic concepts and the application of the First Law of Thermodynamics.

One of the most powerful applications of mass-and-energy balance analysis is to incorporate system interactions and to identify the impact on all system components associated with a proposed change. When investigating the impact of boiler combustion control modifications, it is relatively easy to identify the fuel resource that will be impacted by operational changes and to outline the changes the boiler will experience. However, for steam systems operating with multiple boilers, multiple fuels, steam turbines, and multiple steam pressures, it is much more difficult to identify the impact of a system change. As an example, flash steam from a process unit can be recovered to the low-pressure steam system. This flash steam will reduce the amount of steam that can be passed through power generation steam turbines. Additionally, the boilers will be required to produce less steam, and the mass flow rate of blowdown will be reduced. The recovered flash steam and the reduced blowdown will reduce the required amount of makeup water. This, in turn, will reduce the steam load to the deaerator, further reducing the steam flow through the turbines and from the boilers. This simplistic discussion of a portion of the system impacts demonstrates the absolute necessity of excellent mass-and-energy balance tools.

## 5.2 Kick-Off Meeting

The kick-off meeting should be designed to set the stage for the assessment. The operational and economic constraints the site is operating under should be addressed. This will provide the assessment team the information necessary to evaluate recommendations. The kick-off meeting is also designed to confirm the general timing of the assessment events including mid-assessment briefings, assessment wrap-up meeting, and post-assessment reporting activities. Availability of resources that will be required for the assessment should be confirmed during this meeting. The primary resources are personnel, equipment, instrumentation, and data related.

### 5.3 Facility Orientation Walk-Through

The walk-through is an excellent tool to utilize in the identification of investigation areas. Measurement strategies can be developed based on existing in-place instrumentation and control room information. Additionally, the site interconnections can be identified along with limitations.

### 5.4 Target Areas for Assessment

*(a) Specific Target Areas.* All steam system assessments must focus on all, or a designated subgrouping of system elements involved in steam generation, distribution, end use, and recovery. The specific target areas may include

- *(1)* all steam system(s) including all system components in the facility
- *(2)* one to several, but not all steam systems in the facility
- *(3)* a target subsystem

Often, smaller plants or facilities will have a single steam system. This system may include several boilers and other steam generators, and several end use systems. For this type of system there may be steam distribution at only one pressure throughout the site. Other typically large plants or facilities may have several independent steam systems, each system including steam generating equipment, steam distribution piping, and end use equipment. These systems often operate with multiple steam pressures and several distribution systems. A target subsystem may include equipment in the boiler-house or specific set(s) of end use equipment. Assessments targeting a subsystem will still need analysis of associated steam generating equipment, distribution systems, and possibly components that are outside the immediate realm of the targeted system to determine steam energy cost and impacts.

*(b) Selection of Target Areas.* The selection of target areas for an assessment will be made by the plant or facility manager as guided by

- *(1)* known areas of high steam energy use and cost
- *(2)* resource availability (staff time, funding)
- *(3)* focus on areas other than those surveyed recently by other organizations (e.g., utility company or equipment vendor studies)

*(c) Steam System Assessment.* A steam system assessment requires quantitative analysis of steam generation, distribution, end use, and recovery areas. Target areas and specific data that must be investigated include

- *(1)* boiler fuel
  - *(a)* fuel types and properties
  - *(b)* unit cost (impact cost)
  - *(c)* fuel storage, handling, and conditioning
  - *(d)* fuel consumption
- *(2)* boiler efficiency
  - *(a)* steam generation
    - *(1)* pressure
    - *(2)* temperature
    - *(3)* mass flow rate
  - *(b)* feedwater
    - *(1)* pressure
    - *(2)* temperature
    - *(3)* mass flow rate
  - *(c)* stack loss
    - *(1)* flue gas temperature (and ambient temperature)
    - *(2)* flue gas oxygen content
    - *(3)* flue gas combustibles content
  - *(d)* blowdown loss: mass flow rate, composition markers (e.g., dissolved chemical concentrations)
  - *(e)* shell loss: uninsulated surface area, surface, and ambient air temperatures
  - *(f)* combustible material in fuel wastes (e.g., coal ash loss on ignition)
  - *(g)* energy use in auxiliary equipment [e.g., combustion air fan(s), feedwater pumps, soot blowing]
- *(3)* boiler operation control and characteristics
  - *(a)* master controller
  - *(b)* individual boiler control (automatic/manual)

*(4)* steam distribution system energy losses
*(a)* nominal pipe sizes and lengths, surface temperatures
*(b)* piping and equipment insulation condition, insulation type, insulation covering
*(c)* leaks
*(d)* steam trap operations and management
*(5)* end use
*(a)* steam use rates (or heat duties)
*(b)* energy utilization
*(c)* thermal recovery
*(d)* heat losses from hot surfaces
*(e)* process operation
*(1)* process operating characteristics
*(2)* optimization opportunities (or pinch analysis)
*(6)* combined heat and power operations
*(a)* electricity cost (impact cost)
*(b)* pressure reducing valve flow and operating characteristics
*(c)* backpressure turbine operation
*(1)* inlet, extraction(s), and exhaust temperatures and pressures
*(2)* steam flow rate
*(3)* shaft power (or generated power)
*(d)* condensing turbine operation
*(1)* inlet, extraction(s), and exhaust temperatures and pressures
*(2)* steam flow rate
*(3)* shaft power (or generated power)
*(7)* condensate return
*(a)* steam trap condition
*(b)* quantity of condensate returned
*(c)* condensate return temperature and pressure
*(d)* condensate quality
*(8)* other issues

*(d)* *Required Data.* The required data for the targets listed may be obtained by/from
*(1)* measurements from plant or facility in situ equipment
*(2)* measurement(s) made by the assessment team
*(3)* quantities calculated from mass/energy balance(s) developed by the assessment team
*(4)* original design or manufacturer's specified performance information for the equipment
*(5)* estimates (e.g., uninsulated surface areas) made by the assessment team

The use of this data is discussed in the Guide to Assessment section (section 6) of this document.



## 5.5 Interviews of Specialists, Area Managers, and Operators

When resources permit, interviews of key facility personnel should be conducted by the entire team. Adequate time should be scheduled for interviews. Some open time should also be budgeted in the schedule to accommodate interview sessions that exceed the originally scheduled time. In the case that all issues deemed to be important cannot be covered in the allotted interview time, follow-up interviews with selected individuals should be scheduled.

Along with gathering information on the operation of the facility steam system components, information related to the following issues should also be obtained during the staff interviews:

*(a)* energy projects recently implemented or planned
*(b)* recent reports issued by consultants and steam and other related system service providers
*(c)* planned changes to facility operations (production rates and schedules) potentially impacting steam requirements and to the steam system
*(d)* announced upcoming changes in utility rate schedule(s)

## 5.6 Conduct of Detailed Evaluation With Measurements on Target Equipment/Components

A steam system assessment will include a detailed steam system inspection and performance evaluation based on a set of identified measurements. Sufficient time should be allotted in the assessment schedule for the detailed inspections and measurements needed. In some cases, the assessment team can be divided into groups of one or more team members assigned to inspect designated areas and to make specific measurements. Measurements should be performed carefully and with sufficient attention to detail so as to obtain accurate and reproducible data. Care should be taken to ensure that the magnitude of measured quantities reflects typical steam system operational conditions (e.g., boiler output steam temperature and pressure for typical operating conditions).

In most instances measurement devices properly installed in an appropriate permanent location in the system have the potential to provide the most reliable and accurate measurements of a parameter. However, it is common that a necessary measurement is not provided by an in situ measurement device. Economic or time constraints often result in the use of temporary and possibly portable measuring devices. All measurements should be examined from the standpoint of desired accuracy and the accuracy attainable with the instrumentation used.

One of the most accurate liquid flow measuring strategies is to measure the time required to fill a known volume. Time–volume flow measurements can provide very accurate flow rate indications for *the moment the measurement was taken*. This idea is presented here to focus attention to the fact that almost all measurements vary with respect to time. This fact must be considered in the use of measured data. Conversely, data that have been compiled and averaged can provide an excellent indication of the characteristic of a measurement. However, the variation of the measurement can be a critical parameter when sizing equipment for a recommendation.

It is vitally important to note that steam systems are almost never static. In other words, flow rates, temperatures, pressures, and most all parameters are in a constant state of change. These variations must be considered as vital characteristics of the system operations. These variations must also be considered in measurement strategies. Most often critical measurements will need to be monitored and logged over significant periods of time to establish truly representative data.

All measurements should be attained in a manner that is understood and documented. The description of the measurement methodology should be sufficient to allow the measurement to be repeated. Measurements that can be verified through alternate means are generally desirable. There are standards that have been developed for many measurements — fuel sampling, ash sampling, combustion air heater leakage, and many additional standards. These resources should be consulted to improve data accuracy; ASME is a primary source for these documents.

## 5.7 Identify and Collect Required Data

To complete an accurate system assessment, a large number of measurements are required. These measurements are often developed from in situ measuring instruments that operators and control devices use to manage the steam system components on a continuous basis. Temporary installation of measurement devices is also a common strategy to obtain the desired information. Before using data obtained from any of the instruments [i.e., in situ measurement devices (temporarily installed devices and portable devices)], the assessment team must ensure that sufficient accuracy, precision, and repeatability can be achieved by those instruments.

There are usually several ways to measure any given parameter. Each method has inherent benefits and downsides that must be considered. Critical parameters should be given particular attention because of their impact on the analysis and assessment strategy. Time-based variation in a measured value must be considered in the investigation. Many times data must be captured frequently and over an extended period of time to provide an accurate reflection of operating conditions. As a result, the measurement system selection process must include selection of an appropriate data logging system. Additionally, variation of a parameter across a flow field may require a data matrix to be developed. For example, boiler flue gas may exhibit a significant variation in temperature or oxygen content across the flow field. These same example parameters may vary considerably from one boiler load to another (low-fire versus high-fire).

The number of measurements required to establish confidence in an analysis is a critical point of focus. This can also be a very frustrating determination, because the amount of data required can vary dramatically depending on the type of investigation undertaken. For example, boiler flue gas temperature typically varies with many factors — firing rate being a major factor. In the initial evaluation of this example, boiler flue gas temperature may be observed over the full range of boiler operation to be well below the threshold values that would make the installation of a feedwater economizer economically viable. In this situation the simple measurement set may be deemed appropriate and complete. However, if the initial temperature indications yield an analysis that preliminarily point to the addition of a feedwater economizer, then most probably additional measurements will be required. The temperature measurements will most probably need to be coupled with other measurements, such as boiler load and ambient temperature. This simple example points to the potential intensity of required measurements. In some instances simple average data may be sufficient to complete an appropriate analysis. In other cases a much more integrated analysis will be required to reflect the system impacts accurately.

Calibration strategies should be developed with regard to the importance of a target parameter and the potential error the measurement will introduce in the analysis. Policies and procedures for measurement device calibration should be considered before accepting measured values. If there is doubt about the acceptability of a given measurement, a comparison check against another direct measurement should be completed. The sources of all steam system data obtained should be documented in the assessment notes and maintained as a part of the assessment record.

It is recommended to consult the various documents that have been developed to evaluate the steam system components to establish measurement strategies and calibration requirements. The ASME Performance Test Code 4 is an excellent reference for all measurements required around the boiler. ASME Performance Test Code 19.3 specifically targets temperature measurements. There are many additional standards and guides that can be accessed to aid measurement activities.

**5.7.1 Temperature Measurements.** Temperature measurements are critical to many analyses required in steam system assessments. Temperature is a primary indicator of the energy level of many streams. Temperature is also instrumental in analyzing the condition of insulation covering various equipment components. Commonly, temperature is measured with a thermocouple, resistance temperature device (RTD), fluid-in-glass thermometer, or other direct contact thermometer. These devices can be inserted directly in the fluid stream to get a temperature measurement; this is often the case for near atmospheric pressure fluid streams (such as boiler flue gas).

When the fluid is pressurized, like high-pressure steam, it is common to use these types of thermometer devices inserted in a thermowell. A thermowell is used to provide isolation between a temperature sensor and the environment. A thermowell allows the temperature sensor to be removed and replaced without compromising either the ambient region or the measured fluid. Thermowells are also used in ambient pressure situations to eliminate contamination issues.

The temperature of the outer surface (ambient) of a component (pipe or piece of equipment) can be measured with a direct contact surface thermocouple or RTD. It is also very common to rely on infrared thermometers that do not require direct contact with the solid surface being measured. Infrared thermometers can be coupled with imaging devices (cameras) to provide a two-dimensional temperature indication of the surface.

There are many aspects of infrared temperature measurements that must be addressed, two of which are field-of-view and surface emissivity. The field-of-view of an infrared thermometer refers to the area the instrument is evaluating. The area the instrument is evaluating increases as the instrument is moved farther away. A particular instrument may have a field-of-view that is 1¼ in. in diameter at a distance from the instrument of 1 ft. If the instrument is moved 4 ft from the target, the field-of-view diameter may be 5 in. in diameter. This is very important because infrared thermometers determine the average temperature of all the surfaces that are in the field-of-view of the instrument. To obtain an accurate infrared temperature measurement the object being measured must completely fill the field-of-view of the instrument.

Infrared thermometers measure the infrared energy emitted from a surface and convert this measured energy into temperature. Materials emit infrared energy in proportion to their temperature. However, different materials emit various amounts of infrared energy at the same temperature. This becomes a source of error when taking infrared temperature measurements. There is a maximum (or perfect) amount of radiated energy for an object at a given temperature. A surface that emits this perfect amount of energy is identified as a "blackbody." "Emissivity" is defined as the energy radiated by an object at a given temperature to the energy radiated by a blackbody at the same temperature. The emissivity of a blackbody is 1.0. All materials have emissivity values between 0.0 and 1.0. In general, the higher the emissivity of an object, the easier it is to obtain an accurate temperature measurement. Polished, shiny surfaces will generally have low emissivities (less than 0.3). These surfaces are difficult to measure accurately with infrared devices. Dull, black, and dark surfaces will typically have emissivities between 0.9 and 1.0.

Most infrared thermometers have the capability to compensate for different emissivity values. The difficulty arises in what value to select for a specific surface. An excellent strategy is to "calibrate" the emissivity of a type of material by measuring the surface temperature at one location with an alternate method and adjusting the emissivity compensation of the thermometer to attain the measured value. As an example, the surface temperature of an uninsulated steam pipe can be measured with a surface thermocouple. The infrared thermometer can be calibrated by adjusting the emissivity compensation on the unit until the temperature values match. The compensation value can be used for all similar surfaces. It should be noted that there are tabulated data sets indicating typical emissivities for various materials.

There are many references that provide assistance for temperature measurement. ASME PTC 19.3 is a reference that is specifically targeted to temperature measurements.

**5.7.2 Pressure Measurements.** Pressure measurements are most critical in the evaluation of steam properties. There are many analysis points associated with a steam system (e.g., boiler outlet, turbine inlet, turbine outlet, process supply, deaerator, and many others). Pressure is most commonly measured with Bourdon tube type gauges, electronic gauges that are based on the strain gauge principle (or any other principle), and manometer gauges.

Pressure is measured relative to a base point. In other words, the pressure of a fluid is expressed as greater or less than a known reference pressure. All pressure measurements are a form of "differential pressure" — that is, the numeric difference in the measured pressure versus a known reference pressure. There are three commonly used pressure reference points.

The first pressure reference point is absolute zero pressure, which is the pressure exerted on the walls of a chamber that is totally devoid of molecules. Molecules of a gas or liquid are in constant motion through the volume of their containment vessel. Pressure is the net result of the force of the molecules striking the walls of the container. Absolute zero pressure results when all molecules are removed from the vessel and there is zero net force exerted on the inside walls of the containment vessel. This absolute zero pressure can be reproduced as a point of comparison anywhere. Pressures measured with respect to absolute zero pressure are identified as "absolute pressures."

The second pressure reference point is the pressure of the atmosphere. The surrounding atmosphere exerts pressure because it is a fluid. Pressures measured relative to atmospheric pressure are termed "gauge pressures." Issues encountered with atmospheric pressure are that it is not constant and it is different from place to place. Atmospheric pressure is typically measured with a barometer, which is a form of a manometer.

The third pressure reference point is the pressure of the fluid being measured at a known location. For example, a differential pressure type flow meter indicates flow by measuring the difference in pressure of the fluid pressure upstream of the flow meter and the fluid pressure at some critical location in the flow meter flow path. This type of measurement reference is identified as "differential pressure."

As an example, consider steam passing through an orifice plate type flow meter. Atmospheric pressure, measured by a barometer, is 14.7 lbf/in.$^2$ (absolute). A Bourdon tube pressure gauge is placed in the piping system and measures the upstream steam pressure as 150.0 lbf/in.$^2$ (gauge). In other words, the upstream steam pressure is 150.0 lbf/in.$^2$ greater than atmospheric pressure. Absolute pressure is the gauge measurement and atmospheric pressure added together. As a result, the upstream steam pressure is 164.7 lbf/in.$^2$ (absolute). A pressure gauge installed at the low-pressure point of the orifice plate flow meter indicates a gauge pressure of 148.0 lbf/in.$^2$ (gauge). The differential pressure measured across the flow meter is 2.0 lbf/in.$^2$ (difference).

The units of pressure measurement are often shortened to *psi* to represent *pounds* (lbf) per *square inch* (in.$^2$). The reference condition is added to the abbreviation as psia, psig, and psid — denoting *pounds per square inch absolute*, *pounds per square inch gauge*, and *pounds per square inch difference*, respectively.

There are many references that provide assistance for pressure measurement. ASME PTC 19.2 is a reference that is specifically targeted to pressure measurements.

**5.7.3 Flow Measurements.** Flow measurements often become critical information items in steam system assessments. Steam flow rates, condensate flow rates, and fuel flow rates can be major deciding factors in project analyses. Measuring flow rates can be a difficult task and one that can require a significant expense. Additionally, obtaining accurate flow measurements requires input from experienced engineering and instrumentation personnel. These factors combine to make flow measurement one of the most difficult measurements to obtain.

Many of the flow rates required are of pressurized fluids. In these cases direct flow measurement generally requires a flow meter physically installed in the flow stream. The selection and installation of these flow meters must be well designed to provide accurate results. Additionally, the selection of a flow meter must include a calibration provision. Flow measurements must be appropriately corrected for the pressure, temperature, and composition of the material being measured.

Sometimes direct flow measurement is not practical for a given fluid stream. Mass and energy balance investigations can sometimes be employed to provide a measurement with sufficient accuracy for the desired analysis. As an example, consider the heat exchanger discussed in para. 5.1, Overall Assessment Method. The steam flow rate to the heat exchanger may be a desired measurement. However, there may not be a steam flow meter installed. The air flow through the heat exchanger could be measured with a portable flow measuring device. Commonly a Pitot tube or hot-wire anemometer could be employed to complete a traverse of the air duct. This flow measurement technique would produce a velocity profile across the flow field that can be integrated to produce a total flow rate through the heat exchanger. Once the flow profile is known and the temperature profile is established, then the mass-and-energy analysis can be employed to determine the steam demand. This evaluation is outlined in eqs. (6) through (10).

A simple, versatile, and accurate flow measuring technique for liquids is measurement through the use of filling a known volume during a specified time (*volume-time basis*). Condensate measurements are often obtained by collecting condensate in a known volume container and measuring the time required to fill the volume. This constitutes one of the most accurate flow measurement techniques known.

Portable ultrasonic flow meters have provided successful results for liquids flowing in pipes. These devices can be employed in many applications. Proper training, typically provided by experienced personnel, is required for using ultrasonic flow meters in the field.

Often it is desired to determine the flow rate of a steam leak. Generally, estimating techniques are employed to obtain an order-of-magnitude flow rate. These flow rates can be fairly accurate if the geometry of the leak is regular (an orifice, for example). In these cases there are many empirical based calculations that can be employed to obtain the flow estimate. Compressible flow analysis can also be employed to obtain a more rigorous solution. The accuracy of the estimating techniques diminishes greatly as the leak opening becomes less regular and its dimensions become less defined.

There are many references that provide assistance for flow measurement. ASME PTC 19.5 is a reference that is specifically targeted to flow measurements.

**5.7.4 Chemical Measurements.** Chemical measurements are primarily necessary in the evaluation of the performance of the boiler. Flue gas chemical composition is a critical analysis in the determination of the boiler stack loss. Often the flue gas chemicals are control parameters for the boiler (e.g., combustion zone oxygen control and environmental emissions). The most common flue gas chemical components measured are oxygen, combustible material (often referred to as carbon monoxide), oxides of nitrogen, oxides of sulfur, and particulate matter.

Typically, there are two measurement strategies employed in identifying the chemical components of the fluid stream. First, in situ instrumentation continuously samples and measures the individual components in the stream. Second, portable equipment temporarily samples and measures the components in the stream.

Significant care must be exercised in the selection of the measurement location. Many boilers operate with flue gas pressures less than atmospheric pressure in many sections of the boiler stack. This would result in any opening allowing ambient air (tramp air) to leak into the flue gas stream. If the chemical composition measurement location is downstream of this opening, the sample will be diluted with ambient air and hence, the results may be misleading.

Many water quality and steam quality measurements are completed as chemical concentration measurements. Feedwater and boiler water chemical concentrations can be used to evaluate boiler blowdown rates. All of the chemical analysis measurements must be completed in accordance with standard testing methods.

Blowdown flow rate serves as an excellent example of a system parameter that often varies significantly over a short period of time. Many blowdown control units are on-off control based. In this type of control the blowdown valve opens when boiler water chemical concentrations reach an upper set point. Blowdown is released to reduce the chemical concentrations to the low set point, at which point the blowdown valve is closed. This open-closed cycle may repeat several times each hour. It is obvious that if a flow meter were in place in the blowdown stream, a single point-in-time flow measurement would not provide an indication of the average blowdown rate. The blowdown flow rate would need to be monitored through many cycles and then evaluated to determine the maximum flow, minimum flow, and average flow.

Most blowdown systems do not incorporate a conventional flow meter but rely on boiler chemical data for evaluation of the blowdown rate. However, the analogy of using a point-in-time measurement of chemical concentration to establish the blowdown rate yields the same results as the point-in-time flow measurement example noted here. In short, increasing the observation period and the number of measurements is typically a critical factor in establishing accurate data.

A steam system analysis investigates the energy transfer of the fuel to the steam and the steam to the process. To complete the system analysis, steam properties must be known. Most often the values used to determine properties are the steam temperature and pressure if the steam is superheated. When steam is dry and saturated, pressure or temperature can be utilized to determine the steam properties. If dealing with saturated condensate, pressure and temperature are also the common properties used to provide fluid information. Liquid water, well below the boiling point, requires both temperature and pressure to determine its properties (subcooled liquid). Many other methods can be used to determine steam and water properties, but temperature and pressure are the most common measurements.

Many calculations completed in steam system assessments are investigating the energy associated with an activity. Typically, the thermodynamic property used to determine energy flow is enthalpy. Enthalpy is expressed in terms of specific energy content for a given mass of material; the common English units are British thermal units per pound-mass (Btu/lbm). Enthalpy is typically expressed in equations as the variable $h$.

As stated previously, while temperature and pressure measurements are most commonly used to establish steam properties, many additional avenues can be used to establish steam properties. All of the avenues used to establish steam properties incorporate thermo-physical property data sets of water. It is important to have access to comprehensive thermo-physical property data. There are many forms of property data — tabular, graphical, and computerized. The list that follows contains some steam property data sets that are widely applicable.

– *Steam Tables, Thermodynamic Properties of Water Including Vapor, Liquid, and Solid Phases,* Joseph Keenan, Frederick Keyes, Philip Hill, Joan Moore, John Wiley and Sons, 1969.

– *Thermodynamic Properties, Version 2.0 (software) To Accompany Thermodynamics, Second Edition,* Software by: James Hartley, George Woodruff, Text by: William Black, James Hartley, Harper Collins Publishers, 1990.
– NIST Reference Fluid Thermodynamic and Transport Properties Database: Version 8.0 database, National Institute for Standards and Testing.

**Electrical measurements** can be important when evaluating steam turbines and when identifying auxiliary power requirements (feed-pumps, combustion gas fans, flue gas conditioning devices, and more). Electrical power measurements can be accomplished with excellent accuracy through several measurement points. Electrical power measurements can be estimated with a simplified approach. Typically, alternating current (AC) electrical power measurements utilize the multi-phase power equation as follows:

$$\dot{W} = V\ I\ (\varphi)^{\frac{1}{2}}\ P_f$$

where
$I$ = line current
$P_f$ = power factor
$V$ = line voltage
$\varphi$ = number of phases (often 3)

Power factor is the cosine of the angle between the real and apparent power. Generally, it is easy to measure voltage and relatively easy to measure current. In fact, voltage is somewhat constant for most locations in an electrical system. A problem develops in measuring the power factor. Power factor can vary dramatically based on electrical loading. As an example, a three-phase electric motor producing near design power output may operate with a power factor approaching 0.95. The same motor may operate with a power factor of 0.50 when producing 50% of design power.

As a result, electrical power evaluations must consider the loading of the equipment when establishing a measurement strategy that will yield the desired accuracy. In other words, it may be determined that an estimate of power requirement is all that is necessary for an analysis of a boiler feed-pump (for example). A common analysis strategy would be to measure electrical current, assume the voltage is as stated on the motor nameplate (or possibly measure voltage), and estimate power factor to be 0.95. However, if the feed-pump motor is lightly loaded the power estimate may be significantly in error because the power factor could be very low. These factors should be considered when evaluating electrical power. Power monitoring incorporating voltage, current, and power factor will yield the best results.

**5.7.5 Establish a Steam System Baseline.** Steam system assessments identify the operating performance of the steam system and often recommend modifications to operating characteristics or equipment. The assessment investigations and evaluations are completed under a set of operating conditions that are observed during the assessment. Operating conditions include boiler steam generation, boiler control strategy, turbine operation, process steam demand, condensate recovery, and many additional factors.

The assessment team should aim to complete a steam system assessment during *normal operating conditions*. The term "normal operating conditions" is generally identified with the system operating in typical fashion — nominal equipment loading and control characteristics. This is not to imply that normal operating conditions are static or have only one set of data points. These are just defined as the common operating conditions where possibly most of the operating hours will be accumulated.

Improvement opportunities identified during an assessment are generally evaluated by comparing the improved operating conditions to some set of normal operating conditions — a baseline condition. It is generally thought that the comparison conditions are the conditions observed during the assessment. However, assessments are not always completed during normal or typical operating conditions. Some assessments are completed during periods that do not reflect normal operating conditions. In such circumstances, a successful assessment with appropriate recommendations can still be achieved, but attention must be given to identifying the differences between observed *assessment conditions* and *baseline (normal operating) conditions*.

Selecting the appropriate baseline is very important in an assessment analysis. For example, a steam system assessment may identify that a boiler that was operating with a nominal load of 90% of design could achieve significantly improved performance through the installation of a feedwater economizer. However, this operating condition resulted from the fact that one of the boilers that is typically in operation is out of service due to a tube failure. The boiler targeted for the economizer typically operates with a steam production that is 50% of design and will operate at those conditions in the future too (after the economizer installation and once the "out of service" boiler is repaired and back online). As a result, evaluating the improvement opportunity based on the assessment conditions will overstate the actual impact by 80%. This example is significantly simplified to exhibit the importance of baseline identification.

Additionally, it is noteworthy to realize that baseline conditions could be a set of future or past operating conditions. For example, the site may be operating under normal conditions during the assessment; however, a major expansion in production could be confirmed for the near-term. The operating conditions for the increased production could be selected as the baseline conditions. As an alternate example, a corporate mandate may require a specific reduction in energy consumption with respect to a given production year. The operating conditions for the mandate year could then serve as the baseline conditions.

## 5.8 Develop an Assessment Measurement Plan

It is well understood that measurements are essential to any successful system assessment. It is critical to develop an appropriate measurement plan or strategy for obtaining the required assessment information. Most measurement plans will incorporate in situ instrumentation, portable instrumentation, and estimates, which include indirect measurements using mass-and-energy balances. The measurement plan must also consider the sampling rate and duration of measurements that will appropriately address the operating characteristics of the equipment and the site.

**5.8.1 Measurement With In Place Equipment.** In situ instrumentation typically provides the most straightforward measurement opportunities. Often in situ flow meters, pressure indicators, and temperature sensors compose the foundation of assessment analyses. As a result, it is critical to ensure the accuracy and repeatability of in situ equipment.

**5.8.2 Measurement With Portable Equipment.** Portable measurement equipment in the form of contact thermometers, noncontact thermometers, gas analyzers, flow indicators, and acoustic sensors serve as critical measurement components in most assessments. These devices must be calibrated and well maintained. Additionally, the sensing location is often of critical importance. As an example, if a flue gas sample is taken downstream of a regenerative combustion air heater, the gas sample will be diluted with air in-leakage. It should be noted that some boiler air heater analyses require the measurement of air in-leakage. Most combustion and stack loss analyses are best completed with measurements that minimize the opportunity for in-leakage dilution.

The operation and functionality of the portable instrumentation must be well understood prior to use. For example, an infrared temperature indicator has a finite field of measurement that increases with the distance from the instrument. A given infrared thermometer may be measuring a 1.0-in. diameter field circle 1 ft from the device and a 3.0-in. diameter field circle 3 ft from the device.

**5.8.3 Values Determined by Estimation.** Measurements and analysis data are often determined from estimates and indirect analysis. An example of an estimated evaluation is boiler shell loss — the heat transfer loss from the boiler shell. Typically, a shell loss analysis utilizes a general or representative temperature measurement of each outer surface of the boiler. This characteristic surface temperature is used along with an estimated (or measured) air velocity over the surface to determine the overall heat transfer coefficient. These measured and estimated values are combined in a heat transfer analysis to determine an estimate of the boiler shell loss.

Mass-and-energy balances are also employed to determine measurement points. As an example, steam flow to a steam-to-air heat exchanger can be estimated by measuring the air-flow and the temperature rise of the air. This type of analysis can provide an excellent estimate of steam flow.

Significant care must be exercised in utilizing estimates for critical values. Often estimates are used as a first-order (initial) evaluation to determine if there is a need for additional due diligence.

It should be noted that the measurement and analysis strategies should be completed in a manner that will allow them to be replicated. Repeatability of measurements and analysis is vitally important when verifying the impact of system changes.

## 5.9 Wrap-Up Meeting and Presentation of Initial Findings and Recommendations

The wrap-up meeting is the first formal opportunity to provide a summary presentation of the assessment findings and to identify specific (and potentially economically attractive) recommendations. The factors that will ensure a successful wrap-up meeting, at a minimum, include the following:

*(a)* attendance by all important facility managers to ensure a meaningful evaluation and follow-through on the recommendations.