Related Commercial Resources

CHAPTER 39. TESTING, ADJUSTING, AND BALANCING

SYSTEMS that control the environment in a building change with time and use, and must be rebalanced accordingly. The designer must consider initial and supplementary testing and balancing requirements for commissioning. Complete and accurate operating and maintenance instructions that include intent of design and how to test, adjust, and balance the building systems are essential. Building operating personnel must be well trained, or qualified operating service organizations must be hired to ensure optimum comfort, proper process operations, and economical operation.

This chapter does not suggest which groups or individuals should perform a complete testing, adjusting, and balancing procedure. However, the procedure must produce repeatable results that meet the design intent and the owner's requirements. Overall, one source must be responsible for testing, adjusting, and balancing all systems. As part of this responsibility, the testing organization should check all equipment under field conditions to ensure compliance.

Testing and balancing should be repeated as systems are renovated and changed. Testing boilers and other pressure vessels for compliance with safety codes is not the primary function of the testing and balancing firm; rather, it is to verify and adjust operating conditions in relation to design conditions for flow, temperature, pressure drop, noise, and vibration. ASHRAE *Standard* 111 details procedures not covered in this chapter.

1. TERMINOLOGY

Testing, adjusting, and balancing (TAB) is the process of checking and adjusting all environmental systems in a building to produce and meet the design objectives. This process includes (1) balancing air and water distribution systems, (2) adjusting the total system to provide design quantities, (3) electrical measurement, (4) establishing quantitative performance of all equipment, (5) verifying automatic control system operation and sequences of operation, and (6) sound and vibration measurement. These procedures are accomplished by checking installations for conformity to design, measuring the quantities of fluid that need to flow in the system to meet design specifications, and recording and reporting the results.

The following definitions are used in this chapter. Refer to *ASHRAE Terminology* (www.ashrae.org/ashraeterms) for additional definitions.

Test. Determine quantitative performance of equipment.

Adjust. Regulate the specified fluid flow rate and air patterns at terminal equipment (e.g., reduce fan speed, adjust a damper).

Balance. Proportion flows in the distribution system (submains, branches, and terminals) according to specified design quantities.

Balanced System. A system designed to deliver heat transfer required for occupant comfort or process load at design conditions. A minimum heat transfer of 97% should be provided to the space or load served at design flow. The flow required for minimum heat transfer establishes the system's flow tolerance. The fluid distribution system should be designed to allow flow to maintain the required tolerance and verify its performance.

Bump test. A test consisting of bumping the part and measuring its response. The part will vibrate at its natural frequency, which shows up as a response peak on the analyzer. Usually the bump test is accomplished by placing an accelerometer on the device under test (DUT) and tapping or bumping the DUT with a rubber hammer.

Procedure. An approach to and execution of a sequence of work operations to yield repeatable or predictable results.

Report forms. Test data sheets arranged in logical order for submission and review. They should also form the permanent record to be used as the basis for future TAB work and/or system maintenance.

Terminal. A point where the controlled medium (fluid or energy) enters or leaves the distribution system. In air systems, these may be variable- or constant-volume boxes, registers, grilles, diffusers, louvers, and hoods. In water systems, these may be heat transfer coils, fan-coil units, convectors, or finned-tube radiation or radiant panels.

2. GENERAL CRITERIA

Effective and efficient TAB requires a systematic, thoroughly planned procedure implemented by experienced and qualified staff. All activities, including organization, calibration of instruments, and execution of the work, should be scheduled. Air-side work must be coordinated with water-side and control work. Preparation includes planning and scheduling all procedures, collecting necessary data (including all change orders), reviewing data, studying the system to be worked on, preparing forms, and making preliminary field inspections.

Air leakage in a duct system can significantly reduce performance, so ducts must be designed, constructed, and installed to minimize and control leakage. During construction, all duct systems should be sealed and tested for air leakage.

Water, steam, and pneumatic piping should be tested for leakage, which can harm people and equipment.

Design Considerations

TAB planning begins with design functions, because most of the devices required for adjustments are integral parts of the design and installation. To ensure that proper balance can be achieved, the engineer should show and specify a sufficient number of dampers, valves, flow measuring locations, and flow-balancing devices; these should be properly located in required straight lengths of pipe or duct whenever possible for accurate measurement. Testing depends on system characteristics and layout. Interaction between individual terminals varies with pressures, flow requirements, and control devices.

The design engineer should specify balancing tolerances. Minimum flow tolerances are ±10% for individual terminals and branches in noncritical applications and ±5% for main air ducts. For critical water systems where differential pressures must be maintained, tolerances of ±5% are suggested. For critical air systems, recommendations are the following:

Positive zones:	
Supply air	0 to +10%
Exhaust and return air	0 to –10%
Negative zones:	
Supply air	0 to –10%
Exhaust and return air	0 to +10%

Balancing Devices. Balancing devices should be used to provide maximum flow-limiting ability without causing excessive noise. Flow reduction should be uniform over the entire duct or pipe. Single-blade dampers or butterfly balancing valves are not acceptable for use as balancing devices because of the uneven flow pattern at high pressure drops. Pressure drop across equipment is not an accurate flow measurement but can be used to determine whether the manufacturer design pressure is within specified limits. Liberal use of pressure taps at critical points is recommended.

Stratification

Normal design minimizes conditions causing air turbulence, to produce the least friction, resistance, and consequent pressure loss. Under some conditions, however, air turbulence is desirable and necessary. For example, two airstreams of different temperatures can stratify in smooth, uninterrupted flow conditions. In this situation, design should promote mixing. Return and outdoor airstreams at the inlet side of the air-handling unit tend to stratify where enlargement of the inlet plenum or casing size decreases air velocity. Without a deliberate effort to mix the two airstreams (e.g., in cold climates, placing the outdoor air entry at the top of the plenum and return air at the bottom of the plenum to allow natural mixing), stratification can be carried throughout the system (e.g., filter, coils, eliminators, fans, ducts). Stratification can freeze coils and rupture tubes, and can affect temperature control in plenums, spaces, or both.

Stratification can also be reduced by adding vanes to break up and mix the airstreams. No solution to stratification problems is guaranteed; each condition must be evaluated by field measurements and experimentation.

3. AIR VOLUMETRIC MEASUREMENT METHODS

The pitot tube traverse is the generally accepted method of measuring airflow in ducts. The primary objective for other ways to measure airflow at individual terminals is to establish repeatable measurement procedures that correlate with the pitot tube traverse.

Laboratory tests, data, and techniques prescribed by equipment and air terminal manufacturers must be reviewed and checked for accuracy, applicability, and repeatability of results. Conversion factors that correlate field data with laboratory results must be developed to predict the equipment's actual field performance.

Air Devices

Airflow-measuring instruments should be field verified by comparing to pitot tube traverses to establish correction and/or density factors.

Check correction factors given by air diffuser manufacturers by field measurement and comparing them to actual flow measured by pitot tube traverse.

A capture hood is frequently used to measure device airflows. Correction factors should be established by field measurement and comparison to actual flow measured by pitot tube traverse for hood measurements with varying flow and deflection settings.

Rotating vane anemometers are commonly used to measure airflow from sidewall grilles. Effective areas (correction factors) should be established with the face dampers fully open and deflection set uniformly on all grilles. Correction factors are required when measuring airflow in open ducts (i.e., damper openings and fume hoods [Sauer and Howell 1990]).

Duct Flow

The preferred method of measuring duct volumetric flow is the pitot tube traverse average as detailed in ASHRAE *Standard* 111. When using airflow measuring stations, these airflow measurements should be checked against a pitot tube traverse.

Power input to a fan's driver should be used as only a guide to indicate its delivery; it may also be used to verify performance determined by a reliable method (e.g., pitot tube traverse of system's main) that considers possible system effects. For some fans, the flow rate is not proportional to the power needed to drive them. In some cases, as with forward-curved-blade fans, the same power is required for two or more flow rates. The backward-curved-blade centrifugal fan is the only type with a flow rate that varies directly with power input.

If an installation has an inadequate straight length of ductwork or no ductwork to allow a pitot tube traverse, follow Sauer and Howell's (1990) procedure: use a vane anemometer to read air velocities at multiple points across the face of a coil to determine loss coefficient.

3.1 MIXTURE PLENUMS

Approach conditions are often so unfavorable that the air quantities comprising a mixture (e.g., outdoor and return air) cannot be determined accurately by volumetric measurements. In such cases, the mixture's temperature indicates the balance (proportions) between the component airstreams. Temperatures must be measured carefully to account for stratification, and the difference between outdoor and return temperatures must be greater than 20°F. The temperature of the mixture can be calculated as follows:

$$Q_t t_m = Q_o t_o + Q_r t_r$$

where

Q_t	=	total measured air quantity, %
Q_o	=	outdoor air quantity, %
Q_r	=	return air quantity, %
t_m	=	temperature of outdoor and return mixture, °F
t_o	=	outdoor temperature, °F
t_r	=	return temperature, °F

Pressure Measurement

Measured air pressures include barometric, static, velocity, total, and differential. For field evaluation of air-handling performance, pressure should be measured per ASHRAE *Standard* 111 and analyzed together with manufacturers' fan curves and system effect as predicted by AMCA *Standard* 210. When measured in the field, pressure readings, air quantity, and power input often do not correlate with manufacturers' certified performance curves and proper correction is necessary.

Pressure drops through equipment such as coils, dampers, or filters should not be used to measure airflow. Pressure is an acceptable means of establishing flow volumes only where it is required by, and performed in accordance with, the manufacturer certifying the equipment.

4. INSTRUMENTS

No one established procedure applies to all systems. The bibliography lists sources of additional information.

Air Testing and Balancing

Inclined Manometer. The inclined manometer is made of a single tube, inclined (usually 10:1 slope), to enlarge the reading. Alcohol or special oils are normally used in place of water. Such oils have a lower specific gravity than water which serves to further enlarge the reading. Manometers using these fluids have scales calibrated in in. of water corresponding to the pressure indicated on the oil of a known specific gravity. Recommended for use with pitot tubes or static pressure probes.

The **combination vertical-inclined manometer** is constructed of an inclined fluid column with a scale of 0 to 1.0 or 2.0 in. of water connected to a vertical fluid column with scales of 5 or 10 in. of water. Recommended for use with pitot tubes or static pressure probes.

Limitations:

- Not to be used to measure air velocities less than 600 fpm. A micromanometer, hook gage, or another sensitive instrument should be used to decrease the uncertainty of measurements between 450 and 600 fpm.
- The manometer must be carefully leveled during use and held in a rigid position so that when zero pressure is registered, the end of the meniscus arc of the fluid exactly bisects the center of the zero line.
- Calibration is required. The manometer must be verified by comparison to a recently calibrated reference instrument. If the reading on the instrument to be verified is not within 2% of the reading on the reference instrument, then the manometer must be calibrated by an ISO-certified air speed laboratory before it can be used.

Pitot Tube. A pitot tube, used in conjunction with a manometer, provides a basic method of determining the air velocity within a duct. The typical pitot tube is of a double concentric tube construction, consisting of an 1/8 in. OD inner tube concentrically located inside a 5/16 in. OD outer tube that measures total pressure. The outer static tube has eight equally spaced 0.04 in. diameter holes around the circumference of the outer tube, located 2.5 in. back from the nose or open end of the pitot tube tip. At the base (tube connection) end, the inner tube is open ended, as is the head. The outer tube has a side outlet tube connector perpendicular to the outer tube, directly parallel with and in the same direction as the head end of the pitot static tube. Recommended for measuring an airstream's

- Total pressure, by connecting the inner tube outlet connector to one side of a manometer or draft gage
- Static pressure, by connecting the outer tube side outlet connector to one side of a manometer or draft gage
- Velocity pressure, by connecting both the inner and outer tube connectors to opposite sides of a manometer or draft gage.

When used with a manometer or micromanometer, the pitot tube is very reliable and rugged. Its use as a direct measurement tool is preferred over many other methods for the field measurement of air velocity, system total air, outdoor air, return air quantities, fan static pressure, fan total pressure, and fan outlet velocity pressures where such measured quantities may be required and within the range or capabilities of the instrument.

Instruments that may be used with the pitot static tube include the following:

- Micromanometer: very low pressure differential, less than 1 in. of water
- Inclined manometer: moderate pressure differential, 0 to 10 in. of water
- U-tube manometer: medium pressure differential, greater than 10 in. of water
- Diaphragm-type pressure gage
- Electronic differential pressure meters

Limitations:

- Pitot tubes should not be used to measure velocities below 450 fpm, regardless of the electronic sensors used to identify differentials in pressure, because of the inherent high uncertainties in pitot measurement.
- Accuracy depends on uniformity of flow and completeness of traverse.
- A reasonably large space is required adjacent to duct penetrations for maneuvering the instrument.
- Care is needed to avoid pinching or puncturing instrument tubing.
- Because of the distance between the impact and static holes, the pitot static tube cannot be used to measure flow through orifice-type openings.
- Pitot static tubes are susceptible to plugging in airstreams with heavy dust or moisture loadings.
- Acceptance of the standard pitot static tube rests in its accuracy on the correct determination of the static pressure. The total pressure is not affected by yaw or angularity up to approximately 8° on either side of parallel flow. The static pressure, however, is extremely sensitive to direction of flow.

Accuracy of field measurement. Rigorous error analysis shows that flow rate determinations by the pitot static tube and manometer combination method can range from 5 to 10% error. Experience shows that qualified technicians can obtain measurements within 5 and 10% accuracy of actual flow under good field conditions. It has also been determined that suitable traverse conditions do not always exist, and measurements can then exceed a ±10% error rate.

Chronometric Tachometer. The chronometric tachometer is a hand-held instrument that combines an accurate timer and a revolution counter. After the instrument tip is placed on the rotating shaft, pushing the stopwatch button simultaneously activates the counter and the stopwatch. After the timer has run for either 3 or 6 s, the instrument stops counting revolutions even though it is still in contact with the rotating shaft. The scale is calibrated to give readings directly in rpm. Instrument accuracy is within ±0.5% of full scale. Hand tachometers (e.g., dial face [Eddy current], solid-state with digital readout) can produce instantaneous rpm measurement readings, with accuracy within ±1% of full scale. Tachometers are recommended for determining the speed of any shaft having a countersunk end.

Limitations:

- The shaft end must be accessible and countersunk.
- Calibration is required. Readings must be verified with a recently calibrated chronometric tachometer on each project. If the reading is not within ±2% of the recently calibrated tachometer, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within one-half of a scale division mark.

Clamp-on Volt-Ammeter. This instrument has trigger-operated, clamp-on transformer jaws that allow current readings without interrupting electrical service. Most volt-ammeters have several scale ranges, in amperes and volts. Two voltage test leads are furnished that may be quick-connected to the bottom of the volt-ammeter opposite the end used for measuring current. Some models have a built-in ohmmeter. Instrument accuracy is within ±3% of full scale. Recommended for measuring operating voltages and currents of electric motors and of electric resistance heating coils.

Limitations:

- The proper range must be selected. It is desirable for readings to occur about mid-scale. When in doubt, begin with the highest range for both voltage and current scales. Accuracy of reading low currents can be improved by looping the conductor wire around the jaw once and dividing the current reading by 2.
- Depending on conditions at the point of measurement and the size of the volt-ammeter, access for measurement may be restrictive. Caution is required, particularly when taking measurements under confined conditions.
- To avoid distortion of current readings by other fields, move the meter along the wire to verify that the reading remains constant.
- Calibration is required. Readings must be verified with a recently calibrated clamp-on volt-ammeter on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is ±3% of full scale.

Anemometers. There are several types of anemometers. The **deflecting vane** anemometer consists of a pivoted vane enclosed in a case. As it passes through the anemometer, air exerts a pressure on the vane. Movement of the vane is resisted by a hairspring. The instrument gives instantaneous readings of directional velocities on an indicating scale, and can be supplied with various remote- and direct-connected measuring tips (jets). Recommended for measuring air quantities through both supply and return air terminals using the proper air terminal factor A_k (effective area) for airflow calculation, as well as for indicating low velocities (100 to 300 fpm) where the instrument case itself with the appropriate probe attached is placed in the airstream.

Limitations:

- It should not be used in extremely hot, cold, or contaminated air.
- It is affected by static electricity.
- The instrument duct probe is sensitive to presence and proximity of duct walls, and tends to read high on the suction side and low on the discharge side of a fan.
- Accuracy is affected by position.
- Calibration is required. Readings must be verified with a recently calibrated deflecting vane anemometer on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within ±10% when the instrument is calibrated and used in accordance with the manufacturers' recommendations. Air inlet and outlet device flow A_k factors are a function of duct and damper conditions, which affect velocity immediately before the device. Use under conditions not identical to the manufacturers' test conditions produces measurement error. The instrument must be calibrated in the field for correction factor by pitot tube traverse within the limitations of the system.

The **revolving vane** or **propeller anemometer** can be either mechanical or direct-reading digital. For the **mechanical type**, a mechanical propeller or revolving vane anemometer consists of a light wind-driven wheel connected through a gear train to a set of recording dials that read the linear feet of air passing through the wheel in a measured length of time. The instrument is made in various sizes, but 3, 4, and 5 in. are the most common. Each instrument requires individual calibration. The required instrument accuracy of calibration is 1 to 3% of scale (using a corrective chart). Recommended for measuring supply, return, and exhaust air quantities at air inlets and outlets, as well as air quantities at the faces of return air dampers or openings, total air across the filter or coil face areas, etc.

The **direct-reading digital type** differs from the mechanical type mainly in that it uses a powered electronic circuit to convert a pulse generated by the rotating vane into a small electric current to give a meter reading calibrated directly in air velocity units. Generally, these instruments have microprocessor software to compensate for any nonlinearity. Recommended for measuring supply, return, and exhaust air quantities at air inlets and outlets; air quantities at the faces of return air dampers or openings; total air across the filter or coil face areas, etc.

Limitations:

- For mechanical anemometers, each reading must be corrected by the instrument's calibration chart.
- The air inlet or outlet device manufacturers' specified flow A_k factor for the device must be used in computing air quantities.
- Total inlet area of the instrument must be in the measured airstream.
- It is not suitable for measurement in ducts.
- It is fragile and cannot be used in dusty or corrosive air.
- The instrument has a turbine wheel of very low inertia, so be cautious regarding reliability of readings in nonuniform, turbulent, or stratified airstreams. This is likely to occur downstream of dampers, face-and-bypass coils, or any device that causes turbulence in the airstream being measured.
- The mechanical anemometer is not direct reading and must be timed manually.
- At low velocities, the instrument's friction drag is considerable. To compensate, a gear is commonly used. Thus, the correction is additive at the lower range and subtractive at the upper range, with the least correction in the middle of the range. Most of these instruments are not sensitive enough for use below 200 fpm, although ball-bearing models claim ranges down to 30 fpm. The useful range is from 200 to 2000 fpm.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the anemometer recalibrated by a qualified testing lab.

Accuracy of field measurements:

- Smooth flow: ±5% of reading above 200 fpm. Not recommended for velocities below 200 fpm.
- Nonuniform flow: ±30% (or greater, for direct-reading digital type).
- The instrument must be calibrated in the field for a correction factor by pitot tube traverse within the limitations of the system.

Operation of the **thermal anemometer**, which can be either single point or omnidirectional, depends on the fact that the resistance of a heated element changes with its temperature. As airflows over the element in the probe, the temperature of the element changes from its temperature in still air. The resistance change is indicated as a velocity on the indicating scale of the instrument. Instruments are available using a heated thermocouple, heated thermistor, or a heated wire. They have similar characteristics regarding uses, limitations, and accuracy. Some instruments are also provided with temperature scales that can be used by setting the proper selector button. Others can measure static pressure with provided accessories. Recommended uses include measuring the following:

- Very low air velocities, such as room air currents and airflow in hoods (10 to 600 fpm)
- Air movement at grilles and diffusers

- Velocity measurements in ducts

Limitations:

- The instrument probe is very directional for velocity readings and must be located at the exact location and orientation on the air inlet or outlet device, as specified by the air device manufacturer.
- Probes are subject to fouling by dust and corrosive air.
- The instrument probe must be used in the direction of calibration.
- In general, these instruments should not be used in flammable or explosive atmosphere. However, there are special thermal anemometer probes available for use in these environments.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the anemometer recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is ±3% above 100 fpm. The instrument must be calibrated in the field for correction factor by pitot tube traverse within the limitations of the system.

Thermometers. Dial thermometers are of two general types: stem and flexible capillary. Their dial heads can be 1 3/4 to 5 in., with stainless steel encapsulated temperature sensing elements. Hermetically sealed, they are rust-, dust-, and leakproof and are actuated by sensitive bimetallic helix coils. Some can be field calibrated. Sensing elements range in length from 2 1/2 to 24 in. and are available in many temperature ranges with or without thermometer wells.

Small dial thermometers usually use a bimetallic temperature-sensing element in the stem. Temperature changes cause a change in the twist of the element, and this movement is transmitted to the pointer by a mechanical linkage.

The flexible capillary dial thermometer has a rather large temperature-sensing bulb connected to the instrument with a capillary tube. The instrument contains a Bourdon tube, the same as in pressure gages. The temperature sensing system, consisting of the bulb, capillary tube, and Bourdon tube, is charged with either liquid or gas. Temperature changes at the bulb cause the contained liquid or gas to expand or contract, resulting in changes in the pressure exerted within the Bourdon tube. This causes the pointer to move over a graduated scale as in a pressure gage, except that the thermometer dial is graduated in degrees. The advantage of this type is that it can be used to read temperature in a remote location. In using a dial thermometer, the stem or bulb must be immersed a sufficient distance to allow this part of the thermometer to reach the temperature being measured.

Recommended uses include checking both air and water temperature in ducts and pipe thermometer wells.

Limitations:

- Dial thermometers have a relatively long time lag, so enough time must be allowed for the thermometer to reach equilibrium and the pointer to come to rest.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the dial thermometer recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within one-half of a scale division mark.

There are four basic types of **digital electronic** thermometers: thermocouple, thermistor, resistance temperature detector (RTD), and diode sensors. They consist of a portable, handheld, battery-powered, digital thermometer connected by a short cable to various interchangeable probes that are designed for sensing the temperature of air or other gases, immersion in liquids, or contact with a solid surface. Some instruments have a calibration reference, which allows calibrating out offsets introduced by mechanical shocks, ambient temperature variations, or component drift. Some instruments can switch between I-P and SI units and between resolutions of 0.1 and 1.0. Response times are 1 to 10 s for liquids and solids, and 5 to 50 s for gases. Instrument accuracy is ±0.5°F where the range is below 700°F and ±1.5°F for broader ranges. The lower-range instruments should be used unless the expected measurements will be out of their range.

Recommended uses include all TAB temperature measurements, including air and other gases, liquids, and surfaces of pipes and other components with the appropriate probe. The manufacturers' directions must be followed regarding proper use of probe and maximum allowable temperature for the probe and or thermometer. Equipment is available to measure from –380 to 2250°F. A common range is +14 to +248°F.

Limitations:

- Batteries must be recharged or changed when required.
- In piping applications, it should be remembered that the surface temperature of the pipe is not equal to the fluid temperature and that a relative comparison is more reliable than an absolute reliance on readings at a single circuit or terminal unit.

- Be sure measurement is taken at least as long as response time.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the digital electronic thermometer recalibrated by a qualified testing lab.

Accuracy of field measurements. When properly used, the instrument accuracy shall be attainable in the field.

Fluid Testing and Balancing

Pyrometers. Pyrometers normally used in measurements of surface temperatures in heating and air conditioning applications use a thermocouple as a sensing device and a millivoltmeter (or potentiometer) with a scale calibrated for reading temperatures directly. A variety of types, shapes, and scale ranges are available. The required instrument test accuracy is ±1% of full scale. Recommended uses include

- Balancing water circuits thermally, whenever balancing with flow measurements are not practical.
- For evaluation of some types of boilers, furnaces, ovens, etc., where temperatures are over 100°F.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pyrometer recalibrated by a qualified testing lab.

Limitations. In piping applications, remember that the surface temperature of the conduit is not equal to the fluid temperature, and that a relative comparison is more reliable than an absolute dependence on readings at a single circuit or terminal unit.

Accuracy of field measurements. Accuracy is within one-half of a scale division mark.

Calibrated Pressure Gage. Test gages should be at least Grade A quality; have Bourdon tube assemblies made of stainless steel, alloy steel, monel, or bronze; and have a nonreflecting white face with black lettering conforming to ASME *Standard* B40.1-1985. Test gages are usually 3.5 to 6 in. in diameter, with bottom or back connections. Many dials are available with pressure, vacuum, or compound ranges. Minimum accuracy is within 1% of full scale. Recommended uses are checking pump pressures; coil, chiller, and condenser pressure drops; and pressure drops across orifice plates, venturis, and other flow calibrated devices.

Limitations:

- Anticipated working pressure range is in the middle two-thirds of the instrument's scale range, and the gage should not be exposed to pressures greater than the maximum dial reading. Where there is exposure to vacuum, use compound gage.
- Reduce or eliminate pressure pulsations by installing a snubber or needle valve in waterline.
- Do not mount on vibrating equipment or piping. Wall mounting is preferred; another alternative is to install pressure/temperature test ports that can be used with a portable stem probe and gage (or thermometer) through an elastic, durable, self-sealing material. Cap the test port when not in use for additional sealing security.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within one-half of a scale division mark.

Differential Pressure Gage. This instrument is a dual-inlet, Grade A, dual Bourdon tube pressure gage with a single indicating pointer on the dial face that indicates the pressure differential between two measured pressures. It can be calibrated in psi, in. of water, or in. of mercury. The required instrument accuracy minimum is ±1% of full scale. At lower differential pressure ranges, recommended for use with water hose flexible connectors for water distribution balancing (similar to how a mercury U-tube manometer is used). At higher differential pressure ranges, these instruments can be used in lieu of the two combination high-pressure gages mounted on the mercury U-tube manometer board.

Limitations:

- Some applications require use of a snubber or needle valve. A three-valve cluster for shutoff and bypass is necessary to prevent over-pressure damage when used as a portable test gage.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Accuracy of field measurements. Within one-half of a scale division mark.

Differential Pressure Manifold Gage. This is a single-port, Grade A, Bourdon tube, calibrated test gage attached to the bull of a tee. Each branch is fitted with a tight shutoff ball valve and a length of hose, terminating in a union and nipple for attachment to a conventional gage port at each measuring point. Recommended use is to indicate pressure at each point by alternating valve opening and closing. Using a single gage eliminates potential error from using two separate permanently mounted gages, which are subject to possible vibration damage and differences in calibration.

Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Other Air or Fluid System Measurements

Revolution Counter (Odometer) and Timing Device. The revolution counter is a small handheld counting device that is pressed to the center of a rotating shaft for a period of 30 to 60 s. Reasonable accuracy can be obtained by using a good watch with a sweep second hand or a digital watch if a stopwatch is not available. Recommended use is for determining shaft speed on any shaft having an accessible shaft end with a countersink.

Limitations:

- Not to be used on flat-ended shafts without the correct adaptor. Otherwise, slip and inaccurate readings are inevitable.
- Some types have a clutch engagement in which a certain amount of force is required to activate the recording mechanism.
- Must be used and coordinated with an accurate timepiece.
- Normally cannot be reset to zero; the shaft speed measured is the difference between the initial and final instrument readings divided by the time interval.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the odometer recalibrated by a qualified testing lab.

Accuracy of field measurement. Accuracy is ±2%, when used properly.

Electronic Tachometer (Stroboscope and Photoelectric). The stroboscope has a controlled high-speed electronic flashing light whose frequency is electronically controlled and adjustable. When the frequency of the flashing light is adjusted to equal the frequency of the rotating machine, the machine appears to stand still. This unit need not be in contact with the machine during use. Instrument accuracy is generally within 1.5% of the indicated value, and within 1% if a magnetic pickup is used.

The **solid-state photoelectric tachometer** is an optional instrument that is pointed at the device to be measured and the revolution speed is directly read on the dial face. A reflective paint or material must be spotted on the rotating device; this spot is counted and electronically integrated over time to give an instantaneous reading. The instruments usually have several ranges, and no electrical or physical contact with the device is necessary. Accuracy is within ±1% of the dial scale reading when properly calibrated.

Recommended use is for measuring rotational speeds when instrument contact with the rotating equipment is not feasible.

Limitations:

- Care must be taken to avoid reading multiples of the actual rpm when using the stroboscope. Readings must be started at the lower end of the scale.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the tachometer recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within one-half of a scale division.

Dual-Function Tachometer. This instrument provides both optical and contact measurements of rotation and linear motions. Many allow a choice of ranges, depending on the application. A digital display always indicates the unit of measurement to identify the operating range. A memory button may be used to recall the last, maximum, minimum, and average readings. Compact size and light weight make for easy operation. Recommended use is for measuring rotation speeds by direct contact or by counting the speed of a reflective mark.

Limitations:

- Battery operated

- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the tachometer recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within one-half of a scale division.

Low-Density Fluid U-Tube Manometer. The manometer is a simple, useful way to measure partial vacuum and pressure. In its simplest form, it consists of a U-shaped glass tube partially filled with liquid; a difference in height of the two fluid columns denotes a pressure difference in the two legs. Recommended uses include measuring pressure drops above 1.0 in. of water across filters, coils, eliminators, fans, grilles, and duct sections; and measuring low manifold gas pressures.

Limitations:

- To ensure accuracy, manometer tubes must be chemically cleaned and filled with the correct fluid.
- U-tube manometers cannot be used for readings under 1.0 in. of water.
- Reading accuracy depends on the user's ability to gage the level in each tube simultaneously; this is especially troublesome if surges occur in the flow being measured.

Diaphragm-Type Differential Pressure Gage. A dry diaphragm-operated differential pressure gage that uses a calibrated spring-loaded horseshoe magnet lever operated from the differential pressure on the diaphragm, causing rotation of a highly magnetic permeable helix that positions a pointer on the pressure scale. The pressure gage is operated by magnetic field linkage only, so it is extremely sensitive and accurate; its construction design makes it resistant to shock and vibration. The helix rotates on antishock-mounted sapphire bearings. A zero-calibration screw is located on the plastic cover. Common ranges are 0 to 0.5, 1.0, or 5.0 in. of water. There are approximately 30 available pressure ranges. The minimum accuracy of the instrument is ±2% of full dial range. Recommended for use with pitot tube or with static probe, or with specially constructed induction unit primary air total pressure measuring tip for primary air distribution balancing on high-pressure induction systems.

Limitations:

- Should not be used in preference to liquid or electronic manometer.
- Readings should be made in mid-scale of range.
- Should not be mounted on a vibrating surface.
- Should be held in same position as when zeroed
- Should be checked against a known pressure source with each use
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Smoke Devices. These devices are generally used in special studies of airflow and duct leakage. Candles are available in various sizes and durations of burning time. The chemical element in the smoke is zinc chloride.

Sticks are activated by crushing the end of the device, releasing a smoke stream approximately double that of a cigarette. **Guns** generally use a chemical that readily combines with atmospheric moisture. A **cartridge** produces 500 to 1000 puffs of smoke, or releases the same quantity in a steady stream. **Borazine guns** emit dense white clouds of smoke that tend to remain suspended in air for some time. A valve adjustment regulates the discharge.

Recommended uses include determining the direction and observing the velocity and pattern of airflow in room studies, hoods, filters, etc. Discharge patterns from exhaust systems, driers, hoods, and stacks can be identified.

Limitations:

- Some smoke devices may be toxic, and protective apparatus may be required. After extreme use, special removal efforts may be necessary.
- Smoke devices may activate fire and or smoke alarms in ductwork, computer rooms, or critical areas of the building; or cause panic if occupants are not notified.

Flow Capture Hoods. A conical or pyramid shaped hood may be used to collect the airflow from a terminal and guide it over a flow measuring system which reads directly in cubic feet per minute. The instrument can be a swinging vane anemometer, differential pressure air gage (diaphragm type), manometer, or thermal anemometer. The balancing cone should be tailored for the particular job. The large end of the cone should be sized to fit over the complete air inlet or outlet device and should have a seal to eliminate air leakage. The cone should terminate in a straight section with factory designed and calibrated pressure grids, straighteners, and instruments.

Recommended uses include proportionally balancing air distribution devices.

Limitations:

- Should not be used where discharge velocities exceed 2000 fpm.
- Recognize that the device generally redirects the normal pattern of air discharge and that it contributes an artificially imposed pressure drop in the branch of the air terminal being measured. These may result in a decrease in the delivered airflow of the outlet.
- Contact the air inlet and outlet device manufacturer for details in using this instrument with their devices.
- The instrument must be calibrated for the intended use. For use with supply distribution devices, the instrument should have been calibrated in the supply mode. For use with return distribution devices, the instrument should have been calibrated in the return mode.
- Calibration is required. Flow-measuring instrument and hood assembly should be field checked with a velocity traverse. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Accuracy of field measurements. If the hood is properly shaped and positioned at the air terminal, accuracy of field measurements will be within the limitations of the flow reading instrument.

Micromanometer (Hook Gage). These instruments are designed to read small differences in air pressure accurately and usually have a wide scale range. Most scales read pressures of 0 to 4 in. of water, in hundredths of an inch of water on the vertical scale, and thousandths of an inch of water on a vernier scale.

Different versions of this instrument exist. The most common type contains two glass vials about 2 to 3 in. in diameter. A pointed needle or hook is positioned by a micrometer adjustment until the point dimples the water surface but does not break the surface tension. The difference in level is determined in micrometer readings.

Another variation of this instrument has a single vial or well and an inclined scale. The well is positioned by a micrometer or vernier adjustment. It is very important that all micromanometers, including the electronic units, be accurately leveled.

The solid-state electronic hook gage will measure positive, negative, or differential pressures to ±0.00025 in. of water over a 0 to 2 in. of water range. It can also be used with pitot tubes for accurate measurement of air velocities as low as 350 fpm. Recommended uses include readings at hoods, perforated ceilings, etc.; calibrating other instruments; and measurements of velocities between 450 and 600 fpm, when used with a standard pitot tube.

Limitations:

- Difficult to use with pulsating pressures.
- Stability and leveling requirements make the instrument difficult to use in the field.
- Generally not as sensitive as thermal anemometers below 600 fpm, when used with a standard pitot tube.

Double Reverse Tube. Other names for this device include impact reverse tube, combined reverse tube, and type S tube. It consists of two stainless steel tubes approximately 0.38 in. OD, permanently joined lengthwise. The tubes open facing opposite directions at the probe end with open ends at the base for connection to a manometer. (See Figure 1.) Recommended for use in dirty or wet airstreams where the amount of particulate matter in the airstream impairs the use of a pitot static tube. The instrument can be used to measure total pressure, static pressure, and obtain velocity pressure.

Limitations:

- Requires a large (0.75 in.) duct hole for insertion.
- The tube requires calibration and must be used in the same orientation as calibrated. The flow direction should be marked on the tube.
- The tube cannot be used to measure static pressure directly. It must be connected to two manometers and static pressure must be calculated.
- Tube ends must be kept smooth, clean, and free of burrs.

Accuracy of field measurements. Accuracy for field use of the combination of a double reverse tube with manometers is ±10%.

Clamp-On AC Power Meter (Wattmeter). The clamp-on type power meter has trigger-operated, clamp-on transformer jaws, like a voltammeter. This instrument measures true rms voltage and current, in addition to power in single phase or balanced three phase circuits. Compared with mean value measurement, true rms measurement is especially valuable for distorted waves, such as noise and multiplexed signals. Typical ranges are 20 to 600 V rms, 2 to 200 A rms, and 2 to 200 kW; or 20 to 600 V rms, 0.2 to 20 A rms, and 0.2 to 20 kW. Recommended uses include measurement of single, split-phase, and three-phase power sources. Given motor efficiency and power factor, power draw can be related to motor brake horsepower on a fan or pump curve and the operating point determined.

Limitations:

- Caution is required, particularly when taking measurements under confined conditions.
- Readings below 10% of input range are not recommended.
- Batteries must be checked before use.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within ±1% of reading plus 0.5% of range

Recording Instruments. Recording instruments exist in wide variety, available to record any measurement taken by an instrument, such as dry-bulb temperature, wet-bulb temperature, relative humidity, and operating periods of cycling electrical equipment. The recording charts may be either continuous strip or circular, with chart rotation once every 24 h or 7 days. Some instruments are available with one or more remote bulbs. Recommended for obtaining round-the-clock data on the operation or performance of equipment. They are particularly useful for studying and diagnosing questionable operation in refrigerators, greenhouses, processing rooms, ovens, and comfort air conditioning systems.

Limitations. Some judgment must be used in the application of recording instruments. There are great differences in quality, accuracy, and cost. Care must be used to start the instrument at the correct time of day, and on the right day when a seven-day chart is used. Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the pressure gage recalibrated by a qualified testing lab.

Accuracy of field measurements. Carefully study the manufacturer catalog data for instrument accuracy. It is important to read and observe specific operating instructions to obtain the published accuracy from a given instrument.

Humidity-Measuring Devices. A number of instruments are available to measure the level of moisture in air, including

- Battery-powered hygrometer
- Powered dew point indicator
- Powered psychrometer with built in pump and fan
- Digital psychrometer with built-in reservoir and fan

Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Recommended use varies by type; hygrometers give direct, rapid relative humidity readings, and digital psychrometers provide dry- and wet-bulb depression within approximately 30 s.

Accuracy of field measurements. Hygrometers have an accuracy of ±2 to 3% rh in the 20 to 95% rh range. Psychrometer thermometer readings have an accuracy of ±0.5°F.

Barometer. A barometer measures atmospheric pressure, which is required to correct all airflow readings to standard conditions. A Bourdon tube type with accuracy of 1% of full scale should be used.

Barometric pressure information may also be obtained from weather radio stations or airports in the immediate vicinity. Actual pressure at local elevation must be used for air density calculations.

Fluid System Digital Electronic Differential Pressure Meter. This instrument measures the differential pressure across an element in a system when flow is present, providing digital readings in the range of 3.6 to 600 in. of water. Some instruments include a temperature probe for a range of 32 to 248°F, hoses with snap-on fittings, and automatic air purging. A computer is available for calculating the flow in a range of 0.2 to 4750 gpm and computing the hand wheel setting of compatible valves by proportional balancing procedures. Maximum working pressures can be up to 300 psig.

Recommended uses include measurement of fluid flow, temperature, and differential pressure, as well as computing the setting of compatible valves by proportional balancing procedures.

Limitations:

- The computing feature is limited to compatible valves.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified

testing lab.

Accuracy of field measurements. Accuracy of differential pressure within 12 in. of water or 2% of valve readout (whichever is greater). This same accuracy is true for measurement of flow, done via the computing feature.

Electronic Differential Pressure Meter. This instrument is a portable device which measures differential pressure and gives a digital readout directly in pressure or velocity. Some instruments are also available with adapters and probes to measure flow and temperature. Typical ranges are 0 to 100 in. of water for low-density fluids, and 0 to 2400 in. of water or 0 to 100 psi for high-density fluids. Temperatures can be measured from –55 to 250°F. Recommended for use with a pitot tube, static probe, flow grid, orifice plate, or special balancing valve. Some instruments can also be combined with a flow-measuring hood. Many instruments have memories, averaging capabilities, and printers.

Limitations:

- When air velocities are below 600 fpm, a micromanometer or hook gage should be used. Some instruments of this type have micromanometer accuracies.
- These instruments are battery powered and require checking batteries and replacing or recharging them.
- Some instruments should not be stored below 15°F or operated below 32°F.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements. Experience shows that qualified technicians can obtain measurements that range between ±5 and 10% accuracy under good field conditions. However, good field conditions do not always exist, and measurements can easily exceed ±10% error.

Ultrasonic Flowmeters. This is a device that determines flow through the use of acoustic signals, measured in design units (e.g., gallons per minute). The ultrasonic flow metering station is either an integral part of the piping system or a strap-on meter. In either case, there is no intrusion into the pipe or liquid flow that would generate a pressure drop. There are no moving parts in the flow to maintain or service. Two distinct types of ultrasonic flow meters exist: a transit-time device for HVAC or clear water measurement, and a Doppler-effect device for flows containing a required volume of particulate in the liquid. Recommended use includes measurement of flow in full pipes; these devices are excellent when low or nonexistent pressure drop is a requirement. These are best for larger pipes, and most manufacturers' specifications are based on flows of 1 fps or greater.

Limitations:

- For Doppler flow meters, liquid must contain particulate or gas bubbles.
- Transit-time flowmeters require liquid to be acoustically transparent (implies low particulate content [e.g., typical lake or river water or cleaner]).
- Portable (strap-on) flowmeters require that pipe details (e.g., diameter, wall thickness, material of construction) are known or determinable. Pipe must be acoustically transparent (both concrete and lined pipe are not).
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements.

Doppler Flowmeters:

- Typically within 3 to 5% for strap-on transducers
- Typically within 2 to 3% for integral transducers

Transit-Time Flowmeters:

- Typically within 2 to 3% for strap-on transducers
- Typically within 1 to 2% for integral transducers
- Typically within 0.5 to 1% for integral transducers mounted to a calibrated flow tube

Turbine Flowmeter. This mechanical device uses a wheel placed in the path of the flow. Liquid causes the wheel to turn at speeds relative to the velocity, generating a signal and providing flow information directly in design units (e.g., gallons per minute) or a milliamp output. Recommended for measurement of flow in pipes with clean fluid flow.

Limitations:

- Care must be exercised to maintain the turbine flowmeter, because wear may affect the wheel bearings.
- Bearings may drag if impurities lodge in them.
- Debris can clog or break the wheel.
- Calibration is required. Readings must be verified with a recently calibrated instrument on each project. If the reading is not within ±2% of the recently calibrated instrument, have the instrument recalibrated by a qualified testing lab.

Accuracy of field measurements. Accuracy is within 2%.

Permanently Installed Airflow Measuring Stations. There are two main types of permanent airflow measuring stations. The **velocity pressure array** comprises a fixed array of velocity pressure measuring devices.

Recommended uses. These stations measure the fan total airflow and distribution of air in branch ducts. Other useful measurements include those of outdoor, return, and relief airflow.

Limitations:

- The required length of straight sections upstream and downstream of the measuring device depends on both velocity of airflow and the effects of the nearest obstruction. The location of the airflow measuring station must be in accordance with the manufacturer's recommendations.
- Inlet velocity magnitude, profile temperature, dust, moisture, and gas products may limit the use of airflow measuring stations.

Accuracy of field measurements. Under ideal conditions, a velocity pressure airflow measuring station should produce an accuracy of ±5% plus the error rate of the pressure sensor. Because of sensitivity to disturbances and duct conditions, the manufacturer's duct placement recommendations or *ASHRAE Handbook—Fundamentals* requirements for measurement with technologies based on velocity-pressure equalizing principles should be observed.

The **thermal dispersion array airflow measuring station** obtains velocity measurements directly using independent measurement points in a fixed array before averaging. Communications options allow technicians to download instantaneous point velocity and temperature data independently from the control system. A remote traverse without time lag between samples is possible either using an infrared reading device or over an RS-485 network using BACnet™ or Modbus® protocols. The independent nature of the sensor data allows for accurate duct area averaging.

Recommended uses:

- Direct measurement of outdoor airflow rates (low flow sensitivity and accuracy, wide operating velocity range, wide temperature range, fewer space restrictions)
- Maintaining fixed volumetric differentials for space pressurization control, using its high repeatability
- As a reference for other velocity and temperature instruments because of their stability and factory calibration (higher precision)
- Any conditioned air velocity, volume, or temperature averaging application that would benefit from highly repeatable measurement

Limitations:

- Performance depends on local conditions, velocity sensor density (number/unit area), and type of the nearest obstructions (upstream and downstream).
- Avoid placement downstream of modulating dampers or immediately upstream of a damper that may close completely.
- The discharge side of duct silencers can be problematic when the measuring station is within the absorption distance of a humidifier or wet coil face.

Accuracy of field measurements. Accuracy should be within ±3% of reading, when placement is within the manufacturer's guidelines.

Multifunction Portable Instruments. Digital electronic instruments are available with a wide selection of probes that can be fitted into the various channel ports of a single handheld meter with various uses, accuracies, and limitations. These uses can be singular (e.g., thermohygrometers for temperature and relative humidity) or many. Types of measurements include temperature of air, gas, and liquids with a wide choice of sensing elements, such as thermocouples or RTDs; pressure of air, gas, and liquids with manometers or pitot tubes; differential air pressure, static pressure, or barometric pressure; and differential water pressure or gage pressure. Amongst the specific tools used are wind vane, hot wire, or pitot tube anemometers; optical, inductive, and rotational tachometers; and water and air quality attachments for pH, conductivity, salinity, and mV, O_2, and ion concentration.

Some instruments have both battery and plug-in AC power; recording memory for downloading onto computers or transmission over RS-232 or RS-500 interface; hold, alternating, and averaging circuits for applications as traverses; relative humidity calibrating devices; and other features.

Individual manufacturers must be consulted for details of accuracy, limitations, usage, and response times of the individual measurements.

Instruments should be calibrated in accordance with ASHRAE *Standard* 111 to verify their accuracy and repeatability before use in the field.

5. AIR TESTING, ADJUSTING, AND BALANCING

This section sets forth requirements for system preparation, obtaining data, and system testing and adjusting. These requirements apply to both new and existing HVAC supply, return, and exhaust systems.

System Preparation

Before air system testing, adjusting, and balancing, obtain and verify the following:

- Obtain updated construction drawings, specifications, approved shop drawings and submittals, addenda, bulletins, and change orders related to air systems.
- Prepare field data forms to record testing and balancing process.
- Obtain system leakage rate data where duct leak testing is specified.
- Verify that fans are installed, rotating correctly with proper rpm, controlled to supply the required airflow rate, and that all installation, start-up, lubrication, and safety requirements have been met.
- Check for clean filters properly mounted and sealed.
- Fire, smoke, automatic, and volume control dampers are operable, accessible, and are in an open or normal position.
- Controls are installed, operable, and calibrated.
- Air terminal devices are installed, operable, and accessible.
- Air outlet and inlet devices are installed and accessible.
- Access doors are installed and secured.

Perform the following in accordance with design documents before beginning air system testing, adjusting, and balancing:

- Verify that all dampers are in an open position and all air terminal devices or automatic air volume control devices are in an acceptable mode.
- Verify that all air inlet or outlet deflectors are in the position indicated by the manufacturer when using A_k factors to determine airflow rate, and obtain correction factors for all velocity measuring instruments.
- Verify that all automatic controls in the system are set in the testing mode and all computer programs have been properly loaded (where applicable) and parameters set.

Air System Testing and Adjusting

Perform the following tests and adjustments before beginning the air system balancing:

- Record nameplate data on fan, motor, and air handling cabinet. Also, record sizes of sheaves, belts, and shafts.
- Test and record fan rate to confirm rated speed.
- Measure and record motor-running amperes and voltages.

- Set system in minimum outdoor air mode, then perform a pitot tube velocity traverse of main ducts and adjust fan speeds for total design supply and return airflow rates. Total design flow must include estimated duct leakage plus 5% of system total to allow for balancing effects. Minimum outdoor air quantities, established by pitot tube velocity traverse or other methods, must be maintained during all system modes.
- For special systems such as variable-air-volume or constant-volume pressure-independent air terminal devices, set system static pressure and proceed to test and balance all of the air terminal devices and their downstream air inlet or outlet devices, ensuring that air terminal device inlet pressure is in the correct range. Air terminal device adjustments must be done per manufacturer literature.

The following steps occur after all air terminal devices and related air inlet or outlet devices are balanced:

- Measure and record the static pressure resistance of the duct system and the static pressure drop across coils, filters, etc., in the cabinet or out in the duct system.
- Measure and record the pressures at fan suction and discharge per the pressure rating required, either static or total.
- After the system is balanced, test the system in the maximum outdoor air mode. If motor overloads or airflow rates are excessive, adjust manual dampers to obtain the same conditions as recorded with minimum outdoor air.
- Measure and record outdoor, return, and supply air temperatures with the system set at minimum outdoor air mode at design airflow or diversity and cooling or heating medium set for design flow. Verify coil capacities using the following formulas:

Sensible Heat

$$\text{Btu/h} = \text{cfm} \times 1.08 \times \Delta T$$

where

$$1.08 = \text{constant, } 60 \text{ min/h} \times 0.075 \text{ lb/ft}^3 \times 0.24 \text{ Btu/lb} \cdot {}^\circ\text{F}$$

ΔT = dry-bulb temperature difference between air entering and air leaving the coil. In applications where cfm to conditioned space must be calculated, ΔT is the difference between supply air dry-bulb temperature and room dry-bulb temperature, °F

Total Heat Air-Side

$$\text{Btu/h } t = \text{cfm} \times 4.5 \times \Delta h_{tot}$$

where

4.5 = conversion factor, 60 min/h × 0.075 lb/ft^3

Δh_{tot} = change in total heat content of supply air (enthalpy), in Btu/lb (from wet-bulb temperatures and psychrometric chart or table of properties of mixtures of air and saturated water vapor)

Total Heat Water-Side

$$\text{Btu/h} = \text{gpm} \times 500 \times \Delta T_w$$

where

500 = conversion factor, 60 min/h × 8.33 lb/gallon × 1 Btu/lb · °F

ΔT_w = temperature difference between the entering and leaving water, °F

Air System Balancing

Traverse Procedure. After the air system has been prepared, balance by the procedures set forth. *Note:* When system characteristics prevent design flow rates, balance the system components to equal percentages of design unless otherwise instructed by the design engineer.

Balancing Submain Air Ducts.

- Perform a pitot tube velocity traverse of each submain duct to determine flow rate through each.
- Adjust the main volume control dampers to provide the required flow through each submain air duct.

Balancing Branch Air Ducts. Balance the airflow in each branch duct by the following procedure:

- Beginning at the submain duct closest to the fan, or with the highest percentage of required flow, perform a pitot tube velocity traverse of each branch on that submain duct run.
- Proceeding from the branch with the highest percentage of required flow, adjust the branch volume control dampers to provide the required flow through each branch duct.
- Proceed to the submain duct with the next highest percentage of required flow, and traverse and adjust each branch per the preceding steps.
- Continue until all branches are balanced.

Balancing Air Terminal Device Flow Rates. After obtaining the required airflow rates in submain and branch ducts, balance each air terminal device by the following procedures:

- Starting at the air terminal device with the highest percentage of design flow and ending with the air terminal device having the lowest percentage of design flow, adjust the air terminal device volume control to provide an airflow rate within 10% of design. *Note:* If balanced properly without excess pressure, then at least one air terminal device on each branch should have the volume control damper fully open. Branch dampers may require readjustment.
- Continue until all air terminal devices are balanced to within 10% of design.

Final Adjusting and Balancing. Upon completion of the preceding steps, obtain final measurements as follows:

- Measure and record the final airflow rates at each air terminal device. If adjusting airflow rate through an air terminal device by 5% or less is required to achieve the final setting within 10% of design, it is not necessary to adjust nearby air terminal devices which have been final measured. Otherwise, nearby air terminal devices should be remeasured and adjusted as required.
- Secure, mark, seal, and record the final setting positions of all volume control dampers installed in submain or branch ducts.
- Measure and record the final airflow rates at velocity traverses in main, submain, and branch ducts. Do not adjust related volume control dampers.
- Measure and record the data, as outlined in Section 9.4 (b), (c), (f), and (g).
- Reset all controls for normal operations.

Air-Side Systems. In addition to the applicable procedures already detailed, the following air-side systems require additional balancing procedures as indicated. *Note:* For systems using fan volume controls, balance at less than 100% volume setting to allow for future pressure loss of wet coils, damper movement, or dirty filter, or simulate pressure losses with volume controls at 100%.

Single-Duct, Pressure-Dependent Systems:

- Operate all associated fans.
- Set the air terminal devices being testing on full cooling or for diversity and read all air outlet devices on the system.
- Take static pressures at all system components.
- Proportionally balance the air terminal devices. Start with the air terminal device with the highest percent of design airflow, and proportionally balance all VAV air terminal devices. This is done by setting the air terminal devices to full cooling (maximum airflow) and adjusting the manual volume damper in the inlet to the air terminal device. There must be adequate static pressure at all times in the primary air duct.
- Proportionally balance the air inlet or outlet devices.
- Measure and record the final total airflow rate by pitot tube traverse with system set for maximum airflow.
- Measure and record the data as detailed in Section 8.4 (b), (c), (f), (g), and (i), plus the duct static pressure sensed by the static pressure probe for automatic control of supply duct pressure existing when fan is at design flow rate.
- Reset all controls for normal operation.

- At the completion of balancing,
  - The inlet manual damper to at least one VAV air terminal device in the system will be fully open.
  - At least one damper in each branch duct will be fully open.
  - At least one air inlet or outlet device on each branch duct will be fully open.

Multizone Systems:

- Operate all fans (supply, return, and exhaust) associated with the system at or near design speeds.
- Take initial static pressure measurements at all system components.
- Take total air measurements. Determine total airflow quantity for each zone by pitot tube traverse unless impractical to do so. Take traverses as close to the unit as practical. Where the quantity cannot be obtained by pitot tube traverse, use the sum of the outlet quantities as the total airflow of the zones. Record this information on the report forms. If the system has diversity, determine the diversity ratio and keep the proportion of cooled air to total-volume constant during the balance by setting enough zones to full cooling to equal the design flow through the cooling coil. The remaining zones will be set to minimum flow.
- Check zone damper operation. Modulate the zone mixing dampers and measure the supply fan's motor amperage to ensure that motor overloading does not occur. Check amperage with the system in full cooling, full heating, and economizer modes to determine where maximum brake horsepower occurs. Check that the unit's mixing dampers are operating correctly with minimal leakage. Depending on circumstances, this should be done visually by reading temperatures or using static pressure drops. Also verify that all zone mixing dampers are controlled by the proper space thermostat.
- Set zones being tested on full cooling or for diversity.
- Proportionally balance the zones. Using the data from the pitot tube traverses or reading the outlets, determine which zones are over or under design airflow. If any zone is especially low, investigate and correct for any blockages. To balance the zones, start with the highest zone and adjust each zone's manual balancing damper until the airflow is within 10% of the desired amount.
- To balance the branches, start with the highest branch and adjust the branch damper until the airflow is within 10% of the desired amount. Use the total of the air inlet or outlet devices on the branch or balance with the traverses. After the highest branch is adjusted to within 10% of desired flow, go to the next highest branch and adjust it accordingly. Continue adjusting each branch from the highest to the lowest. After all the branches have been adjusted, go back and recheck each branch, because there is usually some interaction between branches, and readjustment may be necessary.
- After all the branches are adjusted to within 10% of desired airflow, proceed with balancing the air inlet or outlet devices. Read all the air inlet or outlet devices and determine which air inlet or outlet devices have excessively great airflow and adjust them first, regardless of their location. Continue balancing until all the air inlet or outlet devices have been adjusted. Make one or more passes until an acceptable balance is obtained.
- As all the air inlet or outlet devices have been proportionally balanced to each other by branch, an adjustment at the branch damper will increase or decrease all the air inlet or outlet devices on that branch proportionally.
- Measure and record the final total airflow rate by pitot tube traverses in the heating and cooling mode with system set for maximum duct airflow.
- Measure and record the data required in Section 8.4 (b), (c), (f), (g), and (i), plus the duct static pressure sensed by the static pressure probe for automatic control of supply duct pressure existing when fan is at design flow rate.
- Reset all controls for normal operation.
- At the completion of balancing,
  - At least one air inlet or outlet device balancing damper will be fully open on every zone.
  - At least one zone balancing damper will be fully open.
  - Reset the system to normal operating conditions.

Single-Duct, Fan-Powered Pressure-Systems:

Fan configurations vary among air terminal devices in fan-powered systems. The internal fan may be in series with the primary air for continuous airflow, or it may be in parallel with the primary air for intermittent airflow.

Airflow from these fans is controlled by various methods, such as multiple wiring for three-speed control, silicon-controlled rectifiers (SCR) for multiple-speed control, or manual dampers at the fan discharge. Consult the air terminal device manufacturer for the proper operation and setting of the flow control.

- Operate all associated fans.
- Set the air terminal devices being tested on full cooling or for diversity.
- Take static pressures at all system components.
- Proportionally balance all air terminal devices. Start with the air terminal device with the highest percent of design airflow, and proportionally balance all VAV air terminal devices. This is done by setting the air terminal devices to full cooling (maximum airflow) and adjusting the manual volume damper in the inlet to the air terminal device. There must be adequate static pressure at all times in the primary air duct.
- Proportionally balance all air outlet devices.
- Measure and record the final total airflow rate by pitot tube with system set for maximum duct airflow.
- Measure and record the data noted in Section 8.4 (b), (c), (f), (g), and (i) plus the duct static pressure sensed by the static pressure probe for automatic control of supply duct pressure existing when fan is at design flow rate.
- Reset all controls for normal operation.
- At the completion of balancing,
    - The inlet manual damper to at least one VAV air terminal device on each branch duct will be fully open.
    - At least one damper in each branch duct will be fully open.
    - Reset the system to normal operating conditions.

Single-Duct, Fan-Powered Pressure-Independent Systems:

Fan configurations and airflow control for these devices are the same as described in the Single-Duct, Fan-Powered Pressure-Dependent Systems section. Consult the terminal manufacturer for the proper operation and setting of the flow control.

- Operate all associated fans
- Set the air terminal devices being tested on full cooling or for diversity
- Take static pressures at all systemic components
- Proportionally balance all air terminal devices. Consider each air terminal device and associated downstream low-pressure ductwork as a separate, independent system. Verify the action of the thermostat (direct or reverse acting) and the volume damper position (normally closed or normally open). Verify the range of the damper motor as it responds to the velocity controller. Consult the air terminal device manufacturer's data for the required pressure drop range across the air terminal device. The total required inlet static pressure is this drop plus the downstream resistance. Take the static pressure drop across the air terminal device and the inlet static pressure. These readings should be within the required range. Verify that the air terminal device will operate at maximum flow when the inlet static pressure to the air terminal device is within the proper operating range by reading the downstream air outlet devices.
- Proportionally balance all air outlet devices.
- Test the VAV air terminal device for both maximum and minimum airflow as applicable. Consult the manufacturers' recommendations on the proper procedure for setting the velocity controllers if required. Include both quantities on the report.
- Measure and record the final total airflow rate by pitot tube traverses with system set for maximum duct airflow.
- Measure and record the data required in Section 8.4 (b), (c), (f), (g), and (i), plus the duct static pressure sensed by the static pressure probe for automatic control of supply duct pressure existing when fan is at design flow rate.
- Reset all controls for normal operation.
- At the completion of balancing,
    - The inlet manual damper to at least one VAV air terminal device on each branch duct will be fully open.

- At least one damper in each branch duct will be fully open.
- Reset the system to normal operating conditions.

Dual-Duct, Pressure-Independent Systems:

This type of system uses control schemes that supply a varying quantity of heated or cooled air to the space. The hot duct and cold duct each have their own volume controller.

- Operate all associated fans.
- Set the air terminal devices being tested on full cooling or for diversity.
- Take static pressures at all systemic components.
- If all of the air terminal devices are constant volume, set thermostats to obtain all the airflow through the cold ducts. Traverse the main ducts if more than 10% of the rated fan airflow is measured in the hot duct. During the balancing process, find and correct hot valve leakage or crossed box supplies.
- If the air terminal devices have a variable-volume feature, then adjust to full flow via thermostats so the sum total airflow rate of the air terminal devices equals the fan design flow rate during the balancing procedures.
- Test the inlet static pressure at several of the most difficult-to-supply air terminal devices and make system adjustments for adequate pressure at the air terminal device inlet (CV or VAV) to provide the required flow rate through the air terminal device and downstream ductwork.
- With the air terminal device set for 100% cold air delivery and with the hot-duct temperature at least 20°F warmer than the cold duct, test the air terminal device for hot-valve leakage. Measure the temperature of the cold inlet duct air and the supply air temperature at two air outlet devices. If the duct splits at the discharge, measure the temperature at an air outlet device on each branch. If the average supply air temperature at the air outlet device is higher than the cold inlet duct temperature by more than 5% of the difference between cold duct and hot duct temperatures, request the installer to correct the deficiency. Also test for, report, and correct any air mixing deficiencies that result in 3°F or more difference between air outlet device supply temperatures and those supplied by an air terminal device.
- Proportionally balance all air outlet devices. Consider each air terminal device and associated downstream low-pressure ductwork as a separate, independent system. Verify the action of the thermostat (direct or reverse acting) and the volume damper position (normally closed or normally open). Verify the range of the damper motor as it responds to the velocity controller. Consult the air terminal device manufacturer’s data for the required pressure drop range across the air terminal device. The total required inlet static pressure is this drop plus the downstream resistance. Record the static pressure drop across the air terminal device and the inlet static pressure. These readings should be within the required range. Verify that the air terminal device will operate at maximum flow when the inlet static pressure to the air terminal device is within the proper operating range by reading out the downstream air outlet devices.
- Proportionally balance all air outlet devices.
- Test the VAV air terminal device for both maximum and minimum flow as applicable. Consult the manufacturer recommendations on the proper procedure for setting velocity controllers if required. Include both quantities on the report.
- Measure and record the final total airflow rate that velocity traverses in the hot and cold ducts with system set for maximum cold duct airflow.
- Measure and record the data required in Section 8.4 (b), (c), (f), (g), and (i), plus the duct static pressure sensed by the static pressure probe for automatic control of supply duct pressure existing when fan is at design flow rate.
- Reset all controls for normal operation.
- At the completion of balancing,
  - The inlet manual damper to at least one VAV air terminal device on each branch duct will be fully open.
  - At least one damper in each branch duct will be fully open.
  - Reset the system
  - to normal operating conditions.

Laboratory Testing and Balancing:

The first three steps are written as for laboratories where room pressure is negative. The exhaust and supply airflow percentages will switch when the laboratories are designed to be positive pressure.

- For each fume hood, verify by pitot tube traverse that the airflow is between 100 and 110% of design. Design airflow is the volume of exhaust that produces the required face velocity at sash opening (i.e., face velocity × area).
- For each laboratory balance, the supply airflow should be between 90 and 100% of design. Avoid any direct velocity from the ceiling diffuser toward the fume hoods. Verify airflow measurements by establishing correction factors from pitot tube traverses.
- Balance the general exhaust system airflow to between 100 and 110% of design. When flow hoods are used to measure general exhaust airflow rates, care should be taken when reading multiple exhaust grilles that the flow hood does not add restriction, forcing the air to another exhaust grille.
- After the correct airflow for the hood has been established and all exhaust and supply air systems have been balanced, verify that the face velocities do not fall below the design face velocity as directed by the safety officer. Face velocities should be taken at equal areas as described in ASHRAE *Standard* 110.
- Make a sketch of the tested hood indicating each face velocity, the sash opening dimensions (height, width, and area), the position of the internal baffles, the traversed airflow rate, the laboratory room number, and exhaust system number. After the face velocities have been determined to be within the established limits, observe smoke flows into the hood to determine that no reverse flows are present.
- A sticker indicating the inspection test result should be placed on the side of the hood, at the maximum sash height measured, indicating (1) height of sash (in in.), (2) average velocity (fpm), (3) highest velocity (fpm), (4) lowest velocity (fpm, (5) person performing the test, and (6) date of test.

Note in the sketch that all face readings are for reference only. The flow is established by pitot tube traverse. At the present time, there is no way to take the average velocity multiplied by the face area to determine total flow. Each velocity-measuring instrument will require different correction factors, and these corrections are often different for different size hoods of the same type.

If the hood does not pass this requirement a caution tag must be placed on the sash. The caution tag should be a fluorescent orange tag stating that the hood does not meet specified flow requirements, with the date.

Tracking the laboratory control can be done in the following manner by establishing airflows for each air terminal device:

- All hood sashes open, minimum cooling.
- All hood sashes closed, minimum cooling.
- All hood sashes closed, maximum cooling.
- Note velocity at the door during the preceding steps.
- Identify the point at which the hood face velocity falls below its target velocity. (Any time a minimum airflow is set, the hood will track linearly until it reaches the minimum airflow point; face velocity will then increase).
- Indicate flows on a drawing of the laboratory at maximum and minimum conditions and velocities (to be posted at the door).
- Track the entire exhaust system from maximum to minimum flow by observing the static pressure entering the most remote hood exhaust air terminal device and the exhaust fan static pressure controller maintains set point.
- Track the entire supply system from maximum flow to minimum flow, observing the static pressure entering the most remote supply air terminal device. The supply air static pressure controller maintains set point.

Report Information

To be of value to the consulting engineer and owner’s maintenance department, the air-handling report should consist of at least the following items:

1. *Design*
    - Air quantity to be delivered
    - Fan static pressure

- Motor power installed or required
- Percent of outdoor air under minimum conditions
- Fan speed
- Input power required to obtain this air quantity at design static pressure

2. *Installation*

- Equipment manufacturer (indicate model and serial numbers)
- Size of unit installed
- Arrangement of air-handling unit
- Nameplate power and voltage, phase, cycles, and full-load amperes of installed motor

3. *Field tests*

- Fan speed
- Power readings (voltage, amperes of all phases at motor terminals)
- Total pressure differential across unit components
- Fan suction and fan discharge static pressure (equals fan total pressure)
- Plot of actual readings on manufacturer’s fan performance curve to show the installed fan operating point
- Measured airflow rate

  It is important to establish initial static pressures accurately for the air treatment equipment and duct system so that the variation in air quantity caused by filter loading can be calculated. It enables the designer to ensure that the total air quantity is never less than the minimum requirements. Because the design air quantity for peak loading of the filters has already been calculated, it also serves as a check of dirt loading in coils.

4. *Terminal Outlets*

- Outlet by room designation and position
- Manufacture and type
- Size (using manufacturer’s designation to ensure proper factor)
- Manufacturer’s outlet factor (where no factors are available, or field tests indicate listed factors are incorrect, a factor must be determined in the field by traverse of a duct leading to a single outlet); this also applies to capture hood readouts [see ASHRAE *Standard* 111])
- Adjustment pattern for every air outlet

5. 5. *Additional Information (if applicable)*

- Air-handling units
  - - Belt number and size
  - - Drive and driven sheave size
  - - Belt position on adjusted drive sheaves (bottom, middle, and top)
  - - Motor speed under full load
  - - Motor heater size
  - - Filter type and static pressure at initial use and full load; time to replace
  - - Variations of velocity at various points across face of coil
  - - Existence of vortex or discharge dampers, or both
- Distribution system

  - - Unusual duct arrangements
  - - Branch duct static readings in double-duct and induction system
  - - Ceiling pressure readings where plenum ceiling distribution is used; tightness of ceiling
  - - With wind conditions outdoor less than 5 mph, relationship of building to outdoor pressure under both minimum and maximum outdoor air
  - - Induction unit manufacturer and size (including required air quantity and plenum pressures for each unit) and test plenum pressure and resulting primary air delivery from manufacturer's listed curves
- All equipment nameplates visible and easily readable

Many independent firms have developed detailed procedures suitable to their own operations and the area in which they function. These procedures are often available for information and evaluation on request.

6. BALANCING HYDRONIC SYSTEMS

Testing, adjusting, and balancing of hydronic systems has one core principle for functionality: conditioned water (fluid) must be provided to the heat transfer device (coil) so that at design conditions 97% of the coil heat transfer is achieved, while not allowing flow to have a larger tolerance than ±10% of design flow. It is at part load that the designer must take care to assure that a similar type of performance is attainable if desired. Many designers make the assumption that at part load a system will stay balanced. This implies proportionality, which is only ensured if all connected system terminals have the same head loss with respect to the pump. This can, and does, vary based on the type of device used to make adjustments. The condition also varies based on how other devices that affect system flow and head are operated; specifically, variable-speed pumping can have a major impact on how well fluid gets where it is intended by a distribution system at design and part load.

When other design options (e.g., diversity) are used, and where the pump (and possibly the piping system) are not sized to provide connected flow load as based on the required design flow rate for each connected terminal, the designer must analyze the system flow under varying load and control conditions and specify a sequence and methodology of test, with expected results, to ensure system operation. The evolution of system design criteria to incorporate higher Δt, reduce required flow rates, and incorporate advanced control strategies (e.g., variable-speed pumping) has increased the sensitivity of the system to slight variations from design. This necessitates additional calculation and analysis to achieve the comfort and energy efficiency conditions required, while protecting the system from potential hazards (e.g., mold growth) and that might in part be affected by a lack of performance in the system operation. This should not imply that there was or is anything wrong with the fundamentals of earlier system design and field adaptation. Those fundamentals provide the basis to apply design principles with modern knowledge, for efficient, well-operated systems. The relationship between flow and heat transfer is at the root of this understanding.

Heat Transfer at Reduced Flow Rate

The traditional heating-only hydronic terminal (200°F, 20°F Δt) gradually reduces heat output as flow is reduced (Figure 1). Decreasing waterflow to 20% of design reduces heat transfer to 65% of that at full design flow. The control valve must reduce waterflow to 10% to reduce heat output to 50%. This relative insensitivity to changing flow rates is because the governing coefficient for heat transfer is the air-side coefficient; a change in internal or water-side coefficient with flow rate does not materially affect the overall heat transfer coefficient. This means (1) heat transfer for water-to-air terminals is established by the mean air-to-water temperature difference, (2) heat transfer is measurably changed, and (3) a change in mean water temperature requires a greater change in waterflow rate. Figure 1 shows the relationship between water-side design criteria and heat transfer.

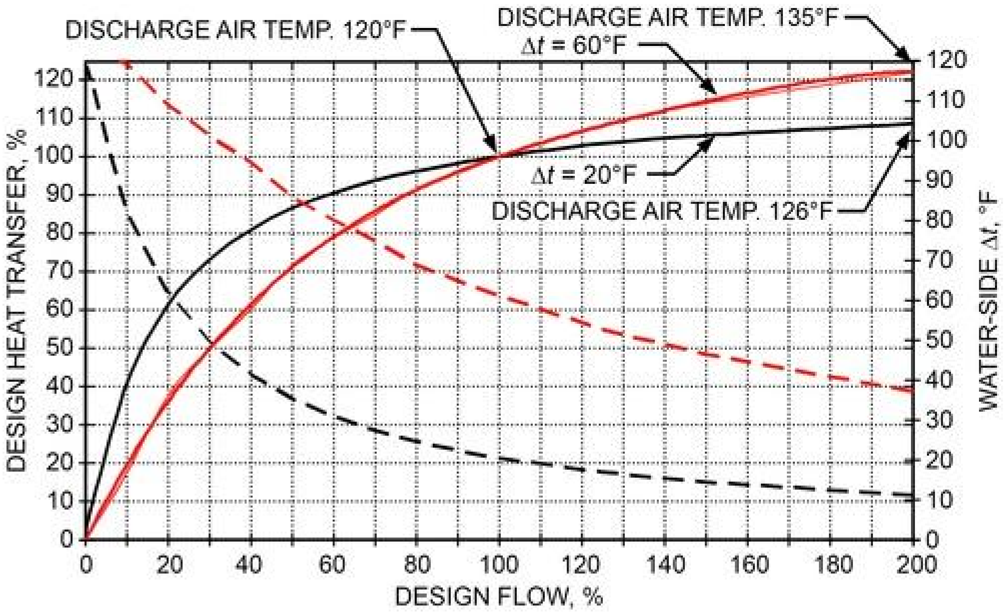

Figure 1. Effects of Flow Variation on Heat Transfer from Hydronic Terminal

The coil was selected for an entering water temperature of 180°F, and design water temperature drops Δ*t* of 20°F and 60°F. The design exit air temperature of the coil is 120°F. Note that with waterflow twice that of design, there is a reasonable amount of temperature difference to indicate overflow. Acceptable industry practice has been to allow for only 10% overflow, and in that case a 20° Δ*t* coil yields a negligible increase in heat transfer (101%) and an equally tough to measure 0.75°F change in departing air temperature. Similarly, the coil with 60°Δ*t* has only 104% of design heat transfer with a 2° increase in leaving air temperature. The designer should not assume that a temperature control system will be able to adequately control any overflows based on sensing the increase in temperature. Though possible if great care is taken to match the control valve to the coil and tune the control loop for proper control, more often than not, this is rarely attained in implementation.

Tests of hydronic coil performance show that when flow is throttled to the coil, the water-side differential temperature of the coil increases with respect to design selection. This applies to both constant-volume and variable-volume air-handling units. In constantly circulated coils that control temperature by changing coil entering water temperature, decreasing source flow to the circuit decreases the water-side differential temperature.

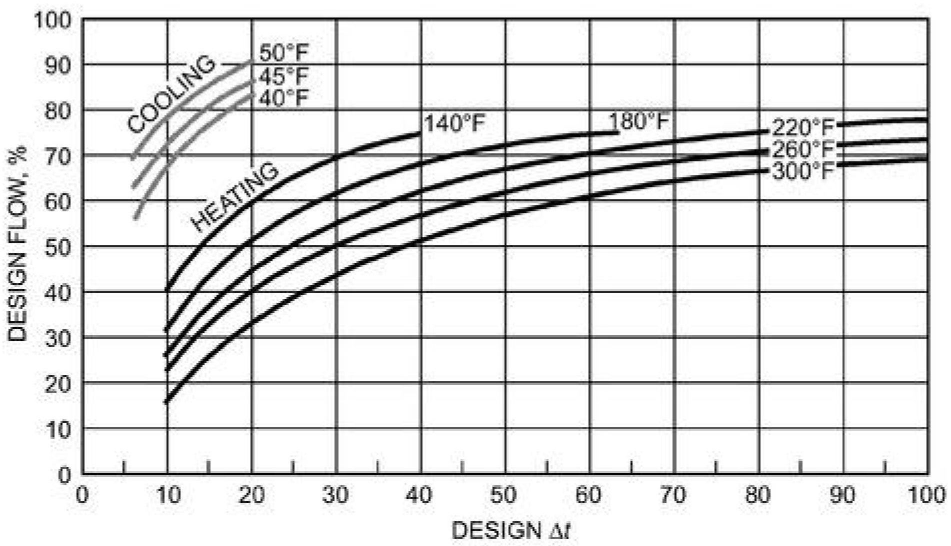

Figure 2. Percent of Design Flow Versus Design Δ*t* to Maintain 90% Terminal Heat Transfer for Various Supply Water Temperatures

A secondary concern applies to heating terminals. Hot water can be supplied at a wide range of temperatures. Inadequate heating capacity caused by actual conditions varying from design or insufficient flow can sometimes be overcome by raising supply water temperature. Designs below the 250°F limit (ASME *Boiler and Pressure Vessel Code*) often add enhanced flexibility to make this adjustment if there is adequate source capacity.

Figure 2 shows the flow variation when 90% terminal capacity is acceptable. Note that heating tolerance decreases with temperature and flow rates and that chilled-water terminals are much less tolerant of flow variation than hot-water terminals.

A third concern also needs to be considered when dual-temperature heating/cooling hydronic systems are employed. These systems are sometimes first started during the heating season. Adequate heating ability in the terminals may suggest that the system is balanced. However, when operated in cooling mode, capacity may vary greatly from that required. Figure 2 shows that 40% of design flow through the terminal provides 90% of design heating with 140°F supply water and a 10°F temperature drop. Increased supply water temperature establishes the same heat transfer at terminal flow rates of less than 40% design.

Sometimes, dual-temperature water systems have decreased flow during the cooling season because of chiller pressure drop; this could cause a flow reduction of 25%. For example, during the cooling season, a terminal that heated satisfactorily would only receive 30% of the design flow rate.

Although the example of reduced flow rate at Δt = 20°F only affects heat transfer by 10%, this reduced heat transfer rate may have the following negative effects:

- Object of the system is to deliver (or remove) heat where required. When flow is reduced from design rate, the system must supply heating or cooling for a longer period to maintain room temperature.
- As load reaches design conditions, the reduced flow rate is unable to maintain room design conditions.
- Control valves with average range ability (30:1) and reasonable authority (β = 0.5) may act as on/off controllers instead of throttling flows to the terminal. The resultant change in riser friction loss may cause overflow or underflow in other system terminals. Attempting to throttle may cause wear on the valve plug or seat because of higher velocities at the vena contracta of the valve. In extreme situations, cavitations may occur.

Terminals with lower water temperature drops have greater tolerance for unbalanced conditions. However, larger waterflows are necessary, requiring larger pipes, pumps, and pumping cost.

Table 1 Load Flow Variation

		Other Load, Order of %		
Load Type	**% Design Flow at 90% Load**	**Sensible**	**Total**	**Latent**
Sensible	65	90	84	58
Total	75	95	90	65
Latent	90	98	95	90

Note: Dual-temperature systems are designed to chilled flow requirements and often operate on a 10°F temperature drop at full-load heating.

System balance becomes more important in terminals with a large temperature difference. Less waterflow is required, which reduces the size of pipes, valves, and pumps, as well as pumping costs. A more linear emission curve gives better system control. If flow varies by more than 5% at design flow conditions, heat transfer can fall off rapidly, ultimately causing poorer control of the wet-bulb temperature and potentially decreasing system air quality.

Heat Transfer at Excessive Flow

Increasing the flow rate above design in an effort to increase heat transfer requires careful consideration. Figures 1 and 3 both show that increasing the flow to 200% of design only increases heat transfer by 6 to 20%. However, the excess flow increases resistance or pressure drop four times and, more importantly, energy draw by a factor of eight using the cube of the original power (from the pump laws).

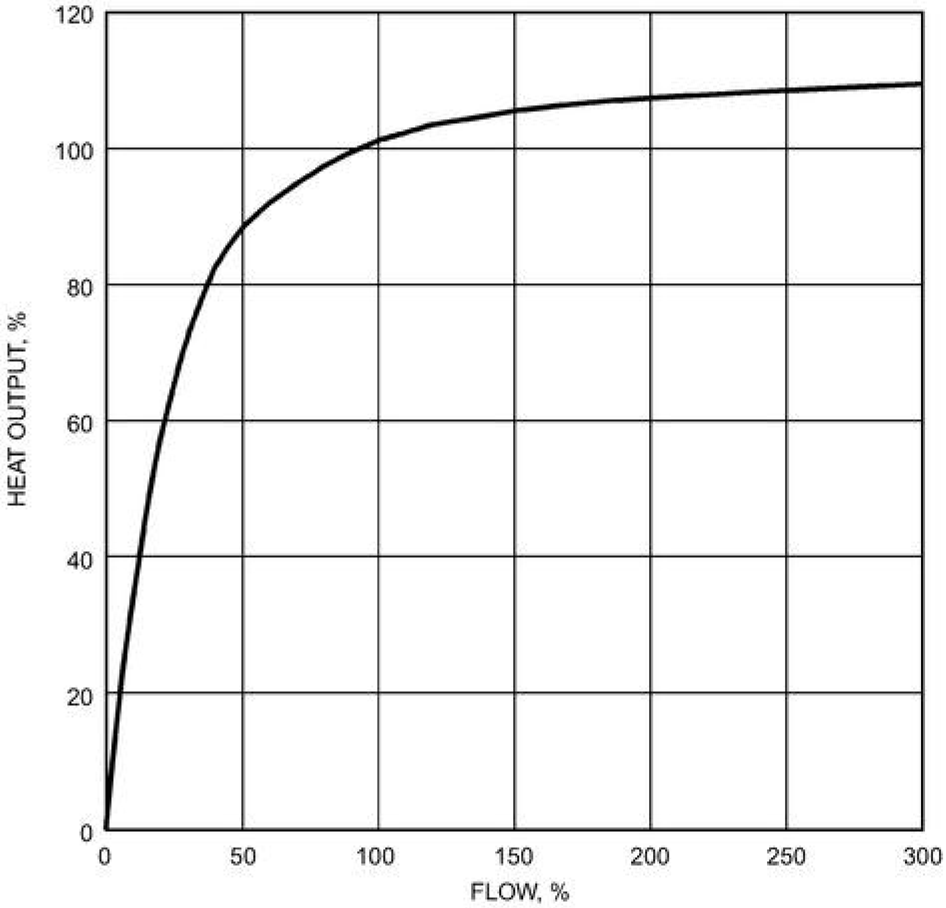

Figure 3. Typical Heating-Coil Heat Transfer Versus Water Flow

Generalized Chilled Water Terminal: Heat Transfer Versus Flow

Heat transfer for a typical chilled-water coil in an air duct versus waterflow rate is shown in Figure 4. The curves are based on AHRI rating points: 45°F inlet water at a 10°F rise with entering air at 80°F db and 67°F wb. The basic curve applies to catalog ratings for lower dry-bulb temperatures providing a consistent entering-air moisture content (e.g., 75°F db, 65°F wb). Changes in inlet water temperature, temperature rise, air velocity, and dry- and wet-bulb temperatures cause terminal performance to deviate from the curves. Figure 4 is only a general representation and does not apply to all chilled-water terminals. Comparing Figure 4 with Figure 1 indicates the similarity of nonlinear heat transfer and flow for both the heating and cooling terminals.

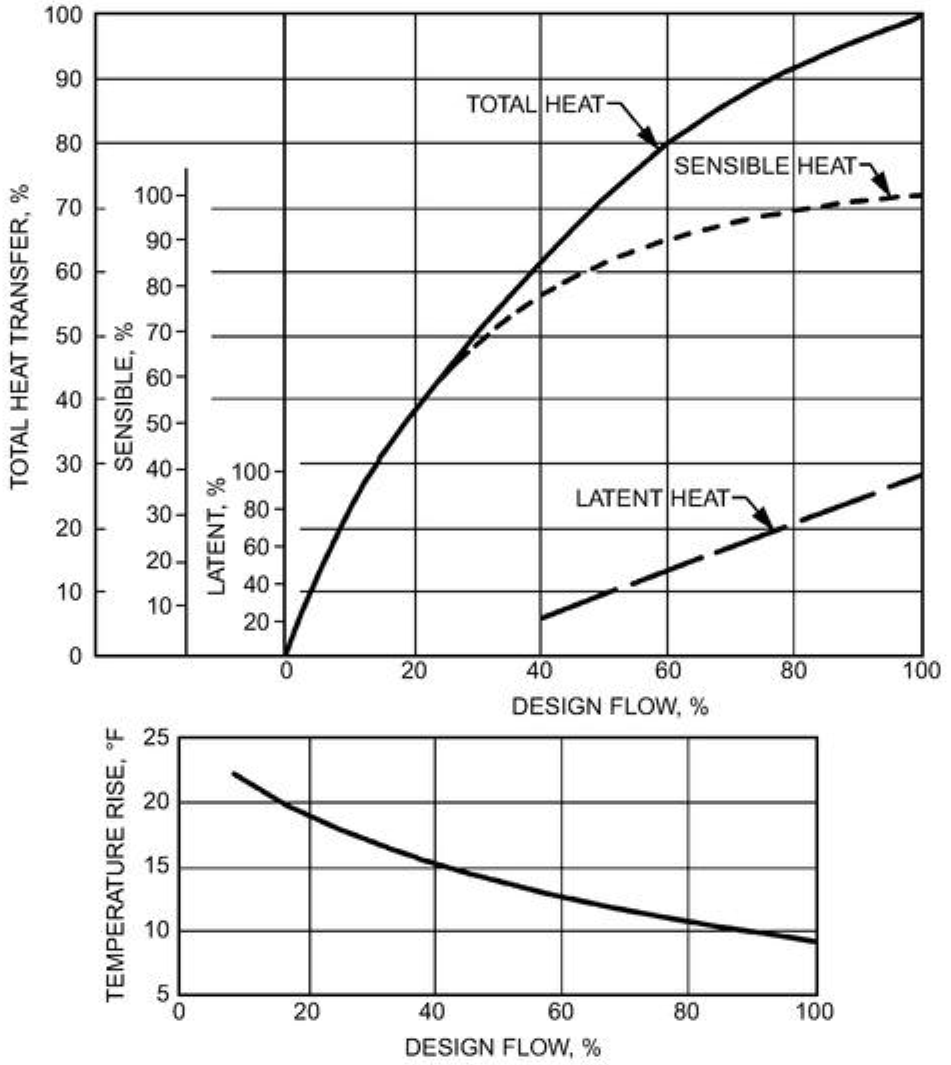

Figure 4. Chilled-Water Terminal Heat Transfer Versus Flow

Table 1 shows that if the coil is selected for the load and flow is reduced to 90% of load, three flow variations can satisfy the reduced load at various sensible and latent combinations. Note that the reduction in flow will not maintain a chilled-water design differential when coil velocity drops below 1.5 fps. This affects chiller loading and unloading.

The coil characteristic shown in Figure 5 is for air that is always recirculated within a space, such as in a fan-coil. Another common (but nonstandard) approach in chilled-water systems is for airflow volume across the coil to vary according to load. Static pressure in the supply duct is controlled by VAV box dampers opening and closing, and some percentage of outdoor air is introduced at entering conditions. With these control modifications, the coil starts to appear more linear, depending on air turndown (determined by load) and variations in dry- and wet-bulb temperatures of the air being introduced. In some cases, as sensible design conditions are approached, reasonable variance in wet-bulb temperature can significantly change heat transfer across the coil. If enthalpy is the control set point, fluid flow may vary by 40% or more of design at the same entering dry-bulb temperature. These common characteristics make fluid flow measurement of a coil (rather than using surrogate indicators such as water-side Δt) important in indicating the system balance.

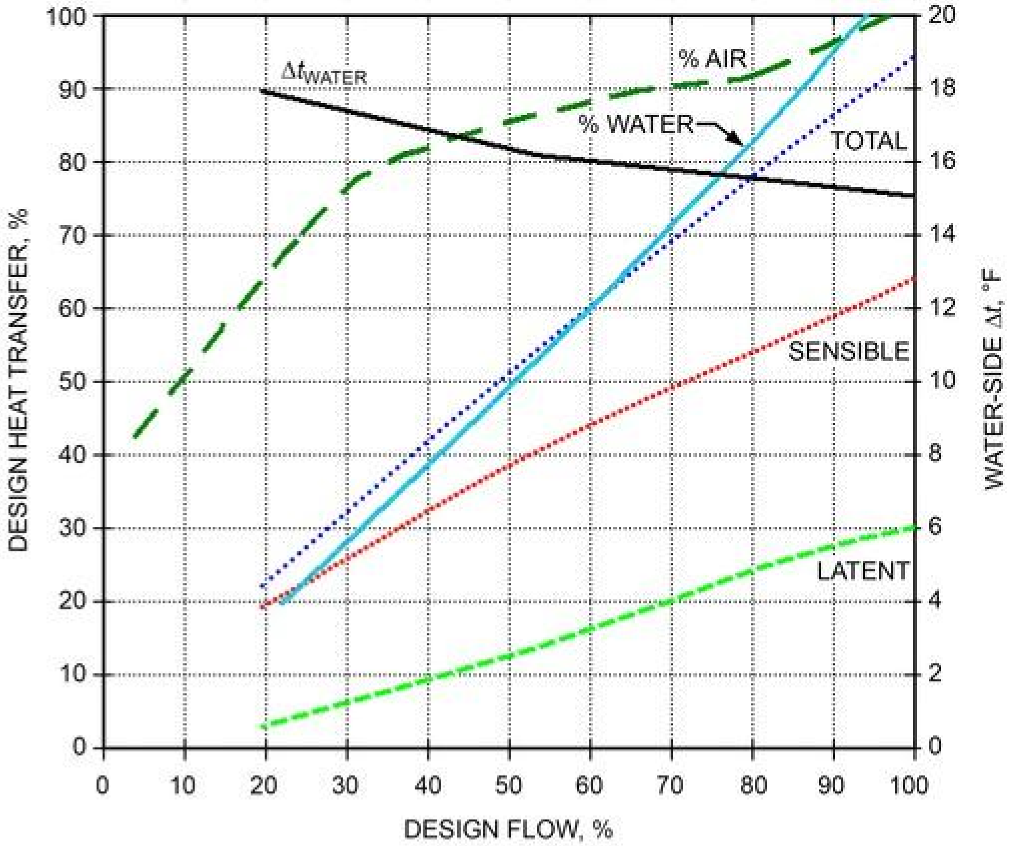

Figure 5. Chilled Water Terminal Heat Transfer Versus Flow for VAV Unit with 20% Outdoor Air

Flow Tolerance and Balance Procedure

The design procedure rests on a design flow rate and an allowable flow tolerance. The designer must define both the terminal's flow rates and feasible flow tolerance, remembering that the cost of balancing rises with tightened flow tolerance. Any overflow increases pumping cost, and any flow decrease reduces the maximum heating or cooling at design conditions.

Water-Side Balancing

Minimum Design Requirements for Hydronic System Installation. Given the effect of flow on heat transfer, comfort, and energy efficiency, each coil must have some form of verifiable flow measurement to enable measurement and verification to properly verify system operation (even if no adjustments are planned). Traditionally, this function was performed by balancing valves, and the required performance was communicated in the written specification and in schematic drawings like the one shown in Figure 6.

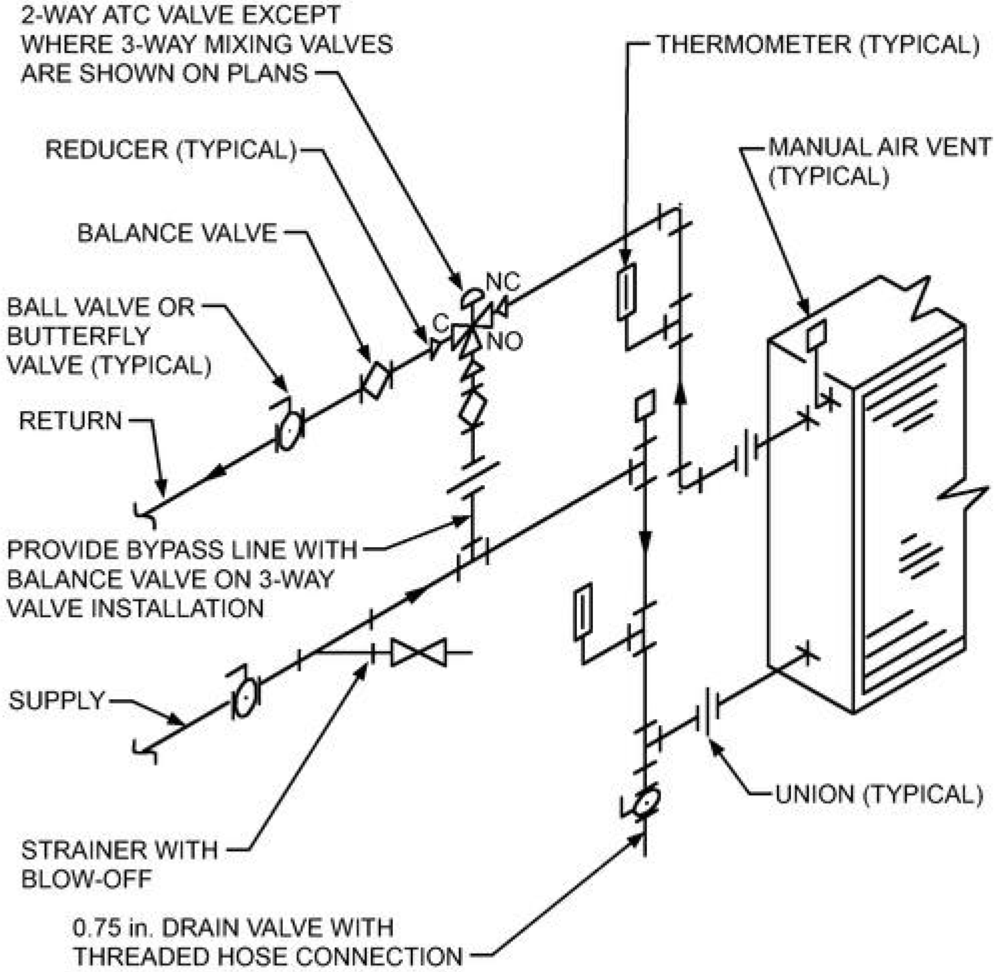

Figure 6. Example of Coil Schematic

The example is not meant to endorse any particular method of control or specification. For example, having thermometers entering and leaving the coil is a nice feature, especially when working on large coils and air-handling units. However, most terminal unit coils (e.g., fan-coils, terminal reheat coils) serving a small temperature control zone have flow rates of 0.5 to 10 gpm, and there are many coils. In that instance, the expense of thermometers is not justified. Alternatively, a measurement device could be installed that allows for the insertion and removal of a temperature sensor into the fluid stream to make a measurement. Note that many fittings and devices are shown. It is very common to find specialty devices installed as an alternative to the specification drawing at the request of the installer, with the object of providing functional performance while increasing the installation efficiency. Typically these are called **hook-up kits** or **coil kits** and are installed with the TAB device and the control valve.

Figure 7 shows the three most common types of devices applied; note that the market can drive subtle variances of their design. There are a few things that are important in applying these devices:

- They should be described in detail in the written specification and shown on the drawings with the required features called out. These devices are not specifically covered by manufacturing standards such as MSS or ANSI standards as other valves and fittings are, and that leaves much open to interpretation.
- Note the required quantity and placement of pressure or temperature (P/T) measurement ports and the minimum required quantity of auxiliary mounting locations (e.g., the strainer valve, which has a P/T port installed, as well as a strainer blowdown and drain valve; in addition, it has a larger auxiliary port for assistance in piping the three-way valve bypass, as well as several alternative ports for relocation of the P/T, additional P/T ports, or other devices that might fit within the constraints of the thread size).
- The devices should specifically be checked for their specific application as a balance device. The devices shown in Figure 7 are all auxiliary piping devices. They provide the functions of shutoff valves, strainers, pressure, and temperature measurement locations or other functions, but they do not provide the calibration of a balancing device for flow measurement or if required adjustment. Balancing devices are distinct, and while the balancing device may serve the purpose of a shutoff valve for one side of the coil (based on code or performance requirements), the auxiliary device does not serve this purpose unless specifically designed to do so.

Balancing Devices. Traditional balancing valves are of two basic styles: static or dynamic. In addition, a simple flow measurement device such as an orifice or venturi could serve the same function, but these are often integrated into the balance valve

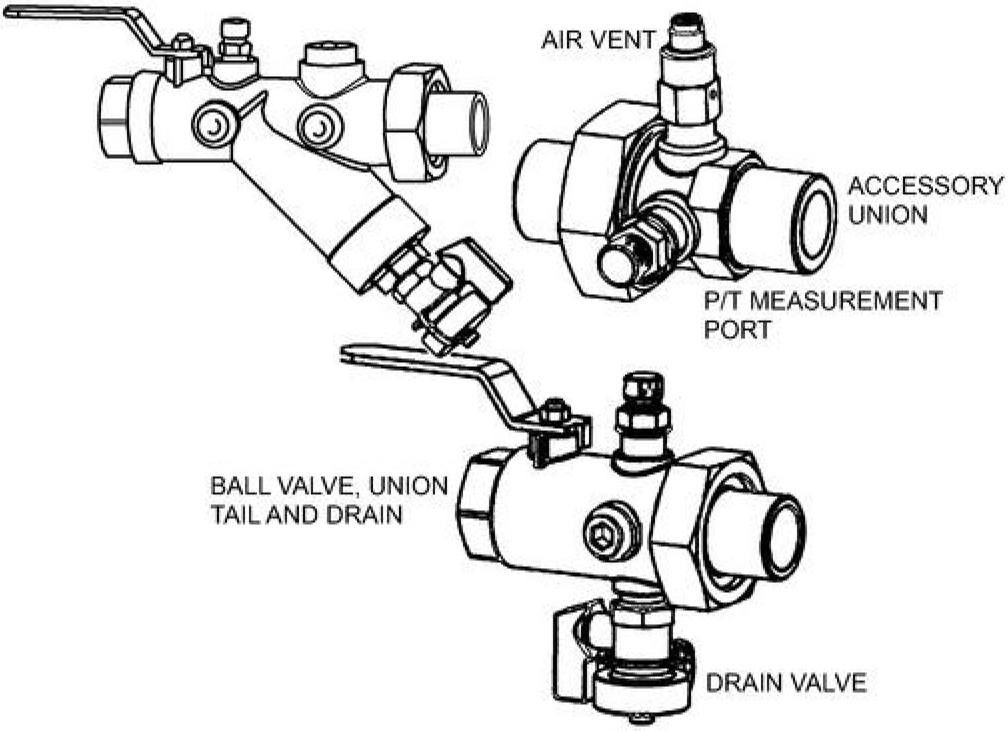

Figure 7. Typical Coil Kit Components

Static Balance Valves. Varieties exist for both operation and measurement. This valve is typically set to a position by a technician and does not self-adjust in operation. Typically, the simplest type of valve has a throttling device able to measure pressure entering and exiting the throttling orifice. Manufacturers publish the performance data associated with the valve using a standardized valve test, such as ISA *Standard* 75.02.01, with adjustment to compensate for the valve design and measurement points. In this manner, the balancing device uses a variable orifice for flow calculation based on the orifice flow coefficient c_V at the operating position. This device generally provides an acceptable flow measurement when wide open, but if care is not exercised to carefully match the differential pressure measurement device range to the flow coefficient of the valve, flow accuracy declines as the valve is closed.

A modified type of static valve uses a fixed orifice for flow calculation combined with a variable orifice for flow adjustment. The fixed orifice may be a simple orifice, venturi profile, or nozzle. Variable orifice measurement requires knowing where the device is set to calculate flow, which may require having to adjust a measurement device each reading. The fixed orifice, on the other hand, does not change each reading, thus giving a direct readout on flow if the measurement device incorporates this calculation and the measurement range is adequate for the measured flow. Remember the square relationship of flow to pressure drop: if 1 gpm is being measured at a pressure drop of 1 psi, then reducing the flow to half gives a measured pressure drop of 0.25 psi. These pressures can become quite small, and finding the proper range sensor is difficult unless care is taken in sizing and design to allow for enough pressure drop to calculate a reasonably accurate flow. Measuring at design flow is important and should be relatively easy to accomplish. However, if the intent is to check the system at part load, especially at flows less than 50% of design, this must be taken into account when selecting the design pressure drop for the measurement device, to make sure the signal is of enough magnitude as to be measurable by the available devices.

The built-in benefit of a static balancing valve is that, when properly field adjusted, all system flow paths have the same head loss (the same as the design head loss calculated for the selection of the pump). This system is therefore proportionally balanced; if flow is too great, all circuits have the same overflow, and if flow is too small, all circuits receive the same percentage of flow. This can be highly advantageous for some system designs. Note that in a system that is properly proportionally balanced, at least one of the balancing valves will be open, providing only the pressure drop required to provide an adequate differential pressure signal for flow calculation. There are no parasitic head losses in the system, because all paths have the same head loss, and maximum flow is limited, reducing flow to only that of design, thus saving pump horsepower and energy.

Dynamic Devices (Automatic Flow Limiters). The process of adjusting the maximum flow in a circuit can be expensive or laborious, but there will be varying differential pressures at each branch that cause excessive flows at design, especially when control valves are selected with little care for required pressure drop at the point of system application. The dynamic device incorporates a system-powered regulator to either vary the open orifice area to keep no more than a specific set point flow, or control the differential pressure across a fixed orifice to accomplish the same function. Like all regulators, these devices rely on machined control areas and engineered springs to set a specific range of operation, and therefore exhibit proportional control of the regulator for the flow, but not proportional regulation of the controlled system (as does the static valve). Typically, these valves operate over a fixed range of differential pressure (e.g., 2 to 32, 2 to 60, or 5 to 60 psid).

A drawback is that these valves do not definitively know the position, and thus the flow coefficient, where the regulator is operating. They also often do not allow for the correct pressures to establish flow. As a result, these devices cannot be used to measure flow at the design condition, and the manufacturer's statement of flow must be taken at face value. Performance is generally reasonable, but there are occasions when suspended construction material can obstruct the working apparatus, blocking flow and giving no indication that there is an issue. It is recommended that when these types of devices are installed, a properly sized fixed orifice device be installed to allow for positive flow measurement.

Pressure Regulators. Regulators are some of the earliest automatic control devices, using various materials and approaches to control specific processes. For example, the simple bimetallic element, which has two physically bonded strips of metal with different coefficients of expansion and contraction, is harnessed into the thermostat, so that when the element heats or cools, the corresponding physical movement of the element actuates a switch or provides control of air pressure to actuate a damper motor or valve. For TAB, system water pressure is directed to both sides of a diaphragm-operated actuator, to open or close a valve. Using a spring on the actuator, a specific pressure set point can be controlled for either a static or differential pressure; by adding other system-powered devices, this basic function can be turned into a flow regulator or other type of control element. Use of regulators on hydronic systems is returning to popularity, with widespread application of variable-speed pumping and designs that attempt to recreate proportional control. (The application of variable speed pumping will be handled separately.)

A differential pressure regulator is typically used, and it is applied either as an independent device across an individual branch, a temperature control valve, or a multiterminal branch. A subset of ΔP regulators is the pressure-independent control valve, which incorporates the ΔP regulator into the body of the temperature control valve to control the pressure drop across the control orifice. In that specific application, whenever system differential pressure at the point of the controlled valve exceeds the regulator pressure set point, the fixed ΔP set point is kept constant. This mimics the same conditions applied when a TC control valve is given the standard flow capacity test, and consequently the valve characteristic is maintained without deviation, because of system hydraulics.

The regulator ΔP is normally less than the pressure drop across the valve assembly as prescribed by the flow capacity test. Manufacturers normally state the controlled range of flow of the valve and the operating ΔP range, and often of the regulator. If the manufacturer states a specific flow coefficient C_v for the valve, this should imply the entire assembly's pressure drop per the standard test method. Whether these devices can be used for flow measurement or verification varies with manufacturer. In some cases, manufacturers provide the ability to measure pressure drop across some portion of the valve. It is common to designate three critical pressures: P1 (upstream pressure), P2 (regulator pressure), and P3 (downstream pressure). If only P1 and P3 are measurable, flow verification cannot be performed because the drop around the controlled orifice is unknown. If P2 and P3 are known and the flow coefficient for the applied position is known (published), it may be possible to verify flow. Some manufacturers incorporate fixed-flow orifices specifically for flow verification. Similar to automatic flow limiters, it is recommended that when these types of devices are installed, a properly sized fixed orifice device be installed (if not included in the valve assemblage) to allow positive flow measurement.

Normal Instrumentation for Field Measurement

Hydronic system measurement tools can be categorized by function: electrical (to deal with pumps), pressure and differential pressure (to establish system settings, pressure losses, and calculate flow rates), temperature (to establish performance levels), and direct-flow instruments (e.g., a strap-on instrument such as a doppler effect type of meter to measure flow directly). In addition, it is useful to apply thermal imagers and vibration analyzers when testing for improper operation and, if the TAB technician is designated to perform alignments, an alignment analyzer.

Electrical Measurements. As a result of the wide application of variable-speed drives to pumps, both a portable oscilloscope and a digital multimeter with required test probes and safety gear and procedures are required to take reasonable and repeatable measurements and establish power use. The oscilloscope is required to measure the voltage and current leaving the drive to the motor and entering the motor and check for imbalance. There are several other measurements that are useful but may not be part of the designated TAB technician's responsibility.

The majority of motors applied to large commercial systems are three-phase motors, and when attached to a speed drive, the frequency of the drive operation is too fast for a digital multimeter. In addition, both the scope and the digital multimeter (DMM) should incorporate a low-pass filter to filter out high frequencies associated with the drive. Note the instrument manufacturer, model, and whether the device includes a low-pass filter measurement documentation. If readings are taken by other technicians at a later time, using meters without the low-pass filter, there may be substantial difference in the reported measurement when no difference actually exists. Because of the function of the drive, voltage measurements can be significantly greater than the nominal 480 V assumed to being measured. Instruments should be rated for 750 to 1000 V to be safe. Analog meters are unacceptable for making these measurements because they lack the required electrical protections and capability to handle power transients. Note that power analyzers may not be substituted for oscilloscopes. Power analyzers are designed to measure supply power lines, but are incapable of measuring drive output power because of the frequencies encountered. The oscilloscope also allows for checking (1) drive setup for output versus load; (2) whether there are overvoltage reflections on the line, which could cause motor winding damage; (3) motor shaft voltages; (4) bearing currents, which can cause fluting of the bearing raceway leading to excess vibration and noise and ultimately leading to reduced motor life; and (5) if there is motor leakage current, which can interfere with control system data acquisition and communications. The digital multimeter is inadequate for many of these measurements, though there are other measurements for which it is very appropriate. Regardless, it too should have the low pass filter to deal with any high frequencies which could lead to errors in measurement.

Pressure Measurement. A broad variety of gages, transmitters, and digital meters exist for the purposes of pressure and differential pressure measurement. The use of the tube-filled manometers was the traditional standard of care, however the indicating fluid was mercury (now a banned substance), so these should never be seen in field application. Most commonly applied still would appear to be a basic mechanical, diaphragm separated dial gage, the device could also be liquid filled. In some cases these might be advantageous due to the inherent simplicity of the device, but what is important is carefully matching the gage range to the expected range of reading, and to ensuring that overpressurization does not influence or damage the gage. The most common problem of the field application of these types of devices is that a user will apply a gage with a reading of 0 to 100 ft of water (up to 45 psi) on a device providing a signal in the range of 0 to 10 in. (up to 0.4 psi).

Digital manometers are also used. In these units, a semiconductor differential pressure sensor or matched pair of gage pressure sensors is used, with either electronic analog circuitry or an application-specific microprocessor to convert the electrical signal from the sensor into usable data by the technician. In many cases, the manufacturers will apply some user adaptability to enter field data that might display the differential pressure, and convert that sensed value to a calculated flow. In other cases, the applied microprocessor has a far greater set of operations, from device databases to instructional methods on making system adjustments. Most important to the balancing process is that an accurate, precise, and appropriate range sensor is applied to the measurement device, and that it is properly compensated for temperature of the working fluid. All sensing devices rely on some electrical interpretation of the physical movement of an object (e.g., diaphragm) in response to changing pressure. The same technologies that are applied to free-standing sensors used in the control process are also applied in the test instrumentation used by balancers. Digital manometers should minimally offer a capability of zeroing the sensor and electrical signal before measurement of the test specimen, and may also offer connection methods to the test specimen that balance the pressure across the device until reading to prevent sensor damage, and ensure that the physical connection device (e.g., tubes) are filled with liquid and vented of air. Test instruments should be regularly checked against a traceable reference standard; allow for regular calibration as required.

Temperature Measurement. Careful system design should always allow for a sensor to be placed directly into a fluid stream, not externally mounted to the pipe. There are a wide variety of mechanical temperature sensing methodologies, such as the traditional liquid-filled thermometer, and bimetallic or vapor-filled elements with a calibrated dial indicator or electronic sensing through RTD, thermistor, or other type of sensing element. Electronic sensing also implies semiconductor devices and implementations that can be quite small, allowing for the carrying or sheathing element to be equally small: the tube that carries the physical sensing device and wires can be diametrically as small as a hypodermic needle (0.06 in. diameter), or the more traditional instant-read type of dial indicator probe, which is slightly greater than 0.13 in. in diameter. Probe size should be checked to ensure that it can be injected into the fluid stream as far as possible (as this may be restricted by entry point). Temperature instruments should be regularly checked against a traceable reference standard, and allow for regular calibration as required and capable.

Less commonly applied, and appropriate for specific applications, are thermographic imagers, which may be handheld and have digital imaging. Though inappropriate for direct fluid temperature measurement, they are invaluable for extra measurements such as showing the face of a heat transfer coil or to indicate faulty points of insulation. On devices such as pumps, they can provide valuable data on motor and bearing operation.

Flow Sensing. The noninvasive flow sensor typically uses a form of ultrasonic detection to establish flow on the interior of a pipe. This is a nontraditional instrument in balancing for several reasons, including setup time and the data required to translate the signal into waterflow. However, in certain application instances, such as measuring main distribution piping, there can be value in spot checking flow rates.

In all of these device categories, there is a wide variety of other technologies which may be applied, especially when those applications are permanent to system operation. However, it is this permanence that makes them less applicable to field testing for TAB. A fluid flow turbine meter may be very good for getting a flow measurement, but adding and then removing the device to the fluid stream (aside from the piping complications) also substantively changes the system pressure drop and flow rate, making the overall readings and adjustments less accurate. This should be accounted for in design. If there are specific devices that the designer feels are more appropriate to the goals that they wish to accomplish, specific mechanical installation techniques and equipment should be incorporated into the design to accommodate those measurements. For example, a removable section of piping could allow for physical checking of the interior pipe surfaces to ensure accuracy for an ultrasonic device.

Expect sensing errors, and the associated error in rational units (e.g. ΔP into volume-per-unit-time flow). Expect that, when the accounting is complete, a gross reading at one point in the system will not be the same as all the individual unit flows when added. When attempting to establish the validity of the reported numbers, it may be necessary to recheck not only the installed devices but also the pipes and fittings. Expect problems, and provide simple logical points of measurement opportunity that allow the anomaly to be traced until satisfaction can be established with the data.

Anecdotal evidence supports the necessity of these precautions. In a 60 story office tower in Chicago, it was known for years that the chilled-water system did not seem to work right and that, in particular, the pumps did not develop the required system flow. After checking all of the installed devices, the building owners eventually installed extra measurement points that allowed enough data to be taken to track anomalies. Eventually, these measurements led to a specific section of pipe. The system was shut down for maintenance, drained, and the suspect pipe was cut open only to find it stuffed with tubes of conduit. Apparently the electrician thought it was a convenient storage spot during construction, and the pipefitters never recognized that it was a mistake, not some form of flow straightener in the pipe, welding it in. These types of errors can (and do) occur with regularity. Catching errors such as this is not the purpose of TAB, but the principles of TAB measurements can be used to address functional problems, as well as the normal system hydraulics.

System Calculation and Specification

Water-side balancing adjustments should be made with a thorough understanding of piping friction loss calculations and measured system pressure losses. It is good practice to show expected losses of pipes, fittings, and terminals, and expected pressures in operation on schematic system drawings (as recommended in ASHRAE *Standard* 111). Designers often use schematic drawings to provide functional representation of a system design, in addition to the dimensional piping plans associated with the building layout drawings. It is suggested that one of these schematics be drawn in a flat connection or ladder-type diagram, as shown in Figure 8. Conceptually, the schematic allows main distribution paths, branch connections, major devices, and the pump, without any piping lines crossing. The drawing serves several purposes: allowing all paths and various system interactions to be easily seen, evaluating opportunities for reverse or gravity flows, easily translating to a spreadsheet for sizing and analysis calculations, quickly and efficiently establishing the required balance adjustments and identifying differences between installed versus design differences (done by the TAB technician), and establishing and communicating more detailed sequences of operation for the control system.

The power of commonly available spreadsheets allows designers to create a straightforward calculation procedure that is easily verifiable by the firm using it. The spreadsheet approach also allows analysis to be performed while sticking to the basics of a system operating at the intersection of its pump and system curves. The accuracy of these methods is reasonably good, and the implementation complexity can be left to the designer of the spreadsheet. For example, to achieve a higher degree of precision in the calculations for fittings, the spreadsheet can account for the influences of geometric plane interaction (as shown by ASHRAE research and detailed in the 2021 *ASHRAE Handbook—Fundamentals*). However, if this is of less concern, the spreadsheet can implement something as simple as *K* factors or fitting TEL. Using Figure 8 as an example, a simple spreadsheet was established to provide design analysis, shown in Figure 9.

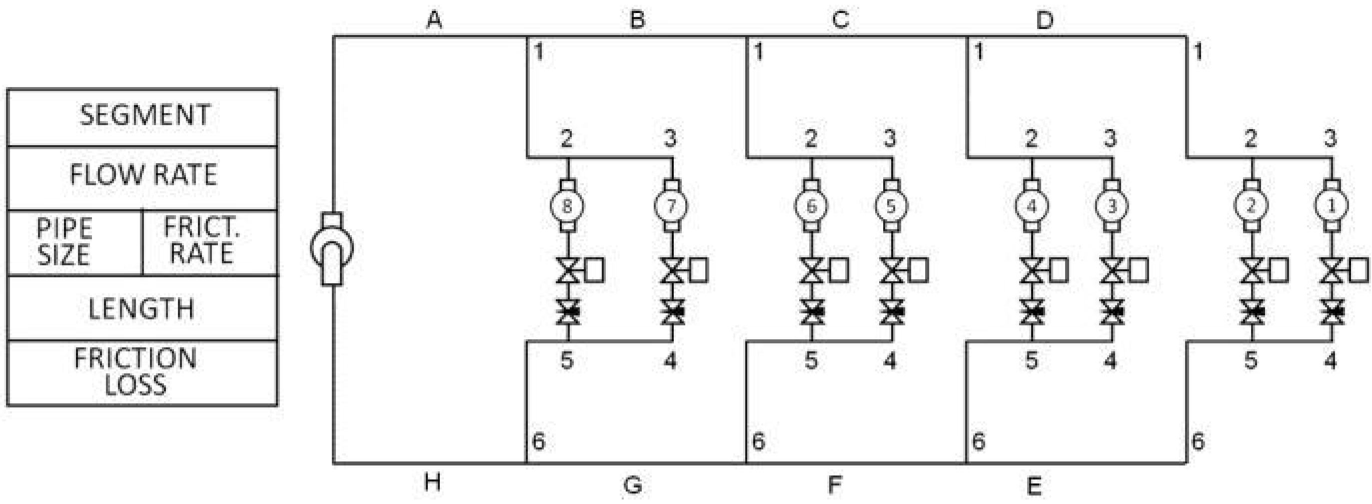

Figure 8. Example of Flat System Schematic Drawing and Labeling for Devices

The spreadsheet allows calculation of the system flow coefficient (analogous to a valve flow coefficient C_V, and outlined in Chapter 47 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*) for showing how various branches will operate. In any pumped piping system, the system will operate at the intersection of the pump and system curve. The system curve is a composite of many system curves, which represent all of the individual paths of waterflow in the system. Each individual path flow coefficient is an indirect sum of the individual component (pipe, fittings, valves, coils, etc.) flow coefficients which may be either implied from calculation or tested under standard test procedures.

The math of the spreadsheet is expressed through algebraic rearrangement of the basic flow equation:

$$\frac{q}{\sqrt{\Delta P}} = C_v \quad \text{or} \quad \left(\frac{q}{C_v}\right)^2 = \Delta P \text{ and } \Delta P \text{ is } \Delta h \tag{1}$$

Given that the system head loss in a closed-loop hydronic system is the total of the single largest path's head loss of pipe, fittings, etc., the sum of the head losses can be rearranged into the requisite components of flow and flow coefficient as shown. As the flow is the same in all paths, the term drops out and an equation that can be solved for the system flow coefficient from the components is realized.

$$\left(\frac{q}{C_v}\right)^2_{Tot} = \left(\frac{q}{C_v}\right)^2_{Pipe} + \left(\frac{q}{C_v}\right)^2_{Coil} + \left(\frac{q}{C_v}\right)^2_{Elbows} + \left(\frac{q}{C_v}\right)^2_{Tees} + \left(\frac{q}{C_v}\right)^2_{Gate} + \left(\frac{q}{C_v}\right)^2_{Bal}\left(\frac{q}{C_v}\right)^2_{Cont}$$

$$\frac{1}{C^2_{V\text{-}Tot}} = \frac{1}{C^2_{V\text{-}Pipe}} + \frac{1}{C^2_{V\text{-}Coil}} + \frac{1}{C^2_{V\text{-}Elbow}} + \frac{1}{C^2_{V\text{-}Tee}} + \frac{1}{C^2_{V\text{-}Gate}} + \frac{1}{C^2_{V\text{-}Bal}} + \frac{1}{C^2_{V\text{-}Cont}} \quad (2)$$

$$\frac{1}{C^2_{V\text{-}Tot}} = \frac{1}{C^2_{V\text{-}1}} + \frac{1}{C^2_{V\text{-}2}} + \cdots + \frac{1}{C^2_{V\text{-}n}}$$

Each individual segment in a flow path will have a path flow rate equal to the design flow rate of the served heat transfer device, and the unique or shared head loss in a segment for that flow. For instance, Coil Path 3 has a flow rate of 100, but the distribution piping segment A-B has a design flow 800 for all eight circuits (only three are shown in Figure 9) and design head loss of 4.03. Using hydronic design principles, all paths see the bulk head loss, and the pump must provide enough energy to overcome these losses, so calculation of the path flow coefficient is as shown in the equation above. All that is being illustrated is the addition of the head losses in each flow path, but doing so as the *X* form of the equation, the flow divided by the flow coefficient squared.

Parallel-path flow coefficients are simply additive, and when used to develop a system curve, they can be plotted to a specific pump curve and the intersection point calculated. This allows for the requirements of the first pass of system adjustment to be determined.

Note that there will be differences in actual measured pressures and those calculated. In keeping with the Bernoulli principles, when fittings and devices are fitted to an installed system, they do not always behave in a perfectly theoretical way. Sometimes there are greater or fewer losses of a combined device, influenced by changes in velocity head and velocity head recovery and exhibited in things like the vicinity of a change in flow direction, and changes in the *X*, *Y*, and *Z* planes of the pipe. These losses can only be tested for, and examples of these influences are demonstrated in ASHRAE research project RP-968 (Rahmeyer 1998) (partially published in Tables 3, 4, and 5 and Figures 2 and 3 in Chapter 22 of the 2021 *ASHRAE Handbook—Fundamentals*). However, this should not be used as a reason not to calculate. The first step should always be to have a more rational quantitative approach by which to direct and decide.

One of the by-products of this type of analysis is the calculation of control valve authority, or the authority of any device used to throttle flow. Simply put, valve authority β is the ratio of control valve pressure drop to the maximum pressure drop of the system that it serves. For a constant-speed pump, ΔP maximum is the pump head, in a variable-speed pumping system, the pressure drop ΔP maximum is the controlled set-point pressure for the pump speed controller The indexing number offers a simple indication of how the valve will perform, but is fairly useless for calculating what the flow would be. However, treated as flow coefficients, the equivalent system flow coefficient is determined as follows.

$$\frac{C_{V\text{-}1} \times C_{V\text{-}2}}{\sqrt{(C_{V\text{-}2})^2 + (C_{V\text{-}1})^2}} = C_{V\text{-}SYST} \quad (3)$$

CIRCUIT 1	A	B	C	D	1-2	2-3	COIL	ATC VALVE	BAL VALVE	4-5	5-6	E	F	G	H		
FLOW	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		
PIPE SIZE	6	5	5	4	4	3		2		3	4	4	5	5	6		
FRICTION	4.03	5.87	2.71	2.27	2.27	2.39				2.39	2.27	2.27	5.87	2.71	4.03		
LENGTH	100	100	100	100	50	50				100	100	100	100	50	50		
HEAD LOSS	4.03	5.87	2.71	2.27	1.135	1.195	15	10.82	2.31	2.39	2.27	2.27	5.87	1.355	2.015		
Cv	75.7	62.7	92.3	100.9	142.7	139.0	39.2	46.2	100.0	98.3	100.9	100.9	62.7	130.6	107.1		PATH Cv
1/Cv^2	0.0001745	0.0002541	0.0001173	9.827E-05	4.913E-05	5.173E-05	0.0006494	0.0004685	0.0001	0.0001035	9.827E-05	9.827E-05	0.0002541	5.866E-05	8.723E-05	0.0026629	19.378683

CIRCUIT 2	A	B	C	D	1-2	2-3	COIL	ATC VALVE	BAL VALVE	4-5	5-6	E	F	G	H		
FLOW	100	100	100	100	100		100	100	100		100	100	100	100	100		
PIPE SIZE	6	5	5	4	4			2			4	4	5	5	6		
FRICTION	4.03	5.87	2.71	2.27	2.27						2.27	2.27	5.87	2.71	4.03		
LENGTH	100	100	100	100	50						100	100	100	50	50		
HEAD LOSS	4.03	5.87	2.71	2.27	1.135		15	10.82	2.31		2.27	2.27	5.87	1.355	2.015		
Cv	75.7	62.7	92.3	100.9	142.7		39.2	46.2	100.0		100.9	100.9	62.7	130.6	107.1		PATH Cv
1/Cv^2	0.0001745	0.0002541	0.0001173	9.827E-05	4.913E-05		0.0006494	0.0004685	0.0001		9.827E-05	9.827E-05	0.0002541	5.866E-05	8.723E-05	0.0025077	19.969333

CIRCUIT 3	A	B	C	D	1-2	2-3	COIL	ATC VALVE	BAL VALVE	4-5	5-6	E	F	G	H		
FLOW	100	100	100		100	100	100	100	100	100	100		100	100	100		
PIPE SIZE	6	5	5		4	3		2		3	4		5	5	6		
FRICTION	4.03	5.87	2.71		2.27	2.39				2.39	2.27		5.87	2.71	4.03		
LENGTH	100	100	100		50	50				100	100		100	50	50		
HEAD LOSS	4.03	5.87	2.71		1.135	1.195	15	10.82	2.31	2.39	2.27		5.87	1.355	2.015		
Cv	75.7	62.7	92.3		142.7	139.0	39.2	46.2	100.0	98.3	100.9		62.7	130.6	107.1		PATH Cv
1/Cv^2	0.0001745	0.0002541	0.0001173		4.913E-05	5.173E-05	0.0006494	0.0004685	0.0001	0.0001035	9.827E-05		0.0002541	5.866E-05	8.723E-05	0.0024663	20.136005

Figure 9. Example Spreadsheet

When the system flow coefficient is calculated for each valve position's flow coefficients, the deviation of a given valve's flow control characteristic may be graphically shown. Figure 10 shows the graphical result for a modified equal-percentage valve at various valve authorities. In the field there may be deviations from this, though the deviation has also been seen in operating systems. Through application of this method of analysis, the effects of balancing the system can be demonstrated for relative effect. It has been anecdotally maintained that application of balancing valves degrades control valve performance, and an example shows this to be partially true, with an unbalanced valve having 22% authority, compared to the same circuit balanced, which has 16%. If the control valve completely opens, under the applied pump differential of 66 ft of water, that is higher than that required for the design flow. Though perfect for the most significant path that the pump was selected for, unbalanced and closer to the pump there will be about 15% overflow. This is shown in Figure 10, based on the example. This overflow is very likely not to be recognized by the valves temperature controller, and the beginning result is that there will be excess pump energy used until the controller is able to respond and reduce flow. For the controls technician, adjusting the proportional setting is harder. In the extreme, controller hunting will occur, continuously opening and closing the valve, over and underflowing. Balancing the poorly sized control valve at reduces the maximum opening overflow. Reduced flow at this condition saves pump energy. Tuning the control loop, however, can only be fixed by selecting the temperature control valve with a better valve authority, which means more design pressure drop, and indirectly increases the design pump head.

From the perspective of cost, reducing flow always saves operating expense (relatively). The use of a balancing device will generally save 10 to 15% (more for systems that have paid little or no attention to the hydronic system details, or that have pumps that provide more head than absolutely required) of the pump energy. Poor control valve authority has a larger energy penalty than balancing maximum flow, because the tuning that is possible leads to valves that generally react to disturbances sooner than the load requires (more flow at load), and at each valve position, more flow is delivered than would be indicated by the characteristic. Pumping costs can be significantly reduced by being able to maintain control valve characteristic (on the order of 50%) with even more energy when considering the operation cost of the source energy provider. In that regard, applying hydronic design options, such as properly zoned secondary pumping, zone differential pressure control, or pressure-independent control valves (PICV) for zone pressure control adds operating benefit.

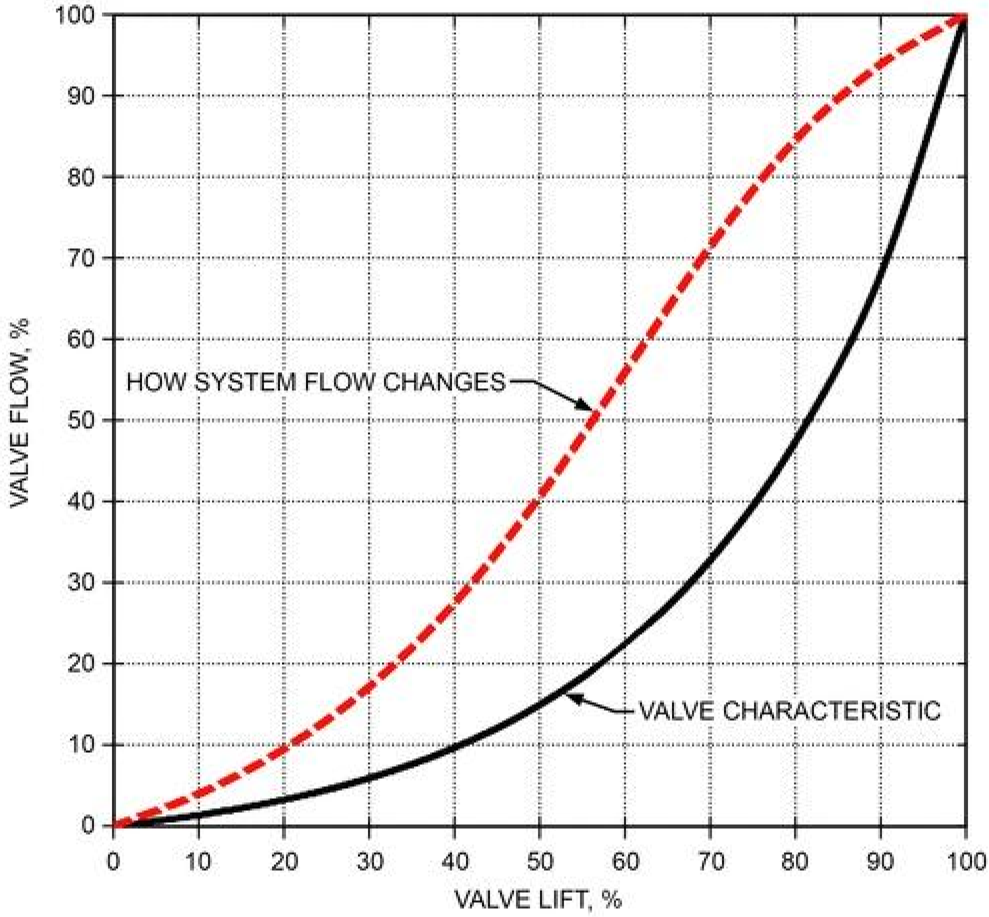

Figure 10. System Flow and Valve Characteristics

Per CSI *Standard* 2305.93, TAB specification requires direct section implementation of equipment, procedures, and specialists. In addition, coordination should be noted in sections on controls, pumps, any installation sections, etc.

Hydronic systems should be tested by direct flow measurement. This method is accurate because it deals with system flow as a function of differential pressures, and avoids compounding errors introduced by temperature difference procedures. To achieve this, each circuit should have some form of inexpensive yet accurate producer of differential pressure related to flow, such as the previously outlined static balancing valve, or a small venturi or orifice measuring station. This requirement could also be a direct reading sensor (as these prices reach competitive levels, or the importance of the measured path requires). Measuring flow at each terminal enables verification of the system operation and, where required, proportional balancing. It also allows matching pump head and flow to actual system requirements and reducing excess flows by trimming the pump impeller or reducing pump speed. Often, reducing pump operating cost pays for the cost of water-side balancing.

Equipment

Proper equipment selection and preplanning are needed to successfully balance hydronic systems. Circumstances sometimes dictate that flow, temperature, and pressure be measured. The designer must specify the waterflow balancing devices and measurement points for installation during construction and use in testing during hydronic system measurement and adjustment. In addition, the designer is well served by specifying the minimum acceptable level for test equipment, which should include full-scale range and accuracy and required calibration. In so specifying, simplicity should be the order of the day. Temperature sensors should be able to fit into the specified measurement ports. Pressure and differential pressure sensing devices should be capable of providing accuracy that, when converted to system flow, falls within the specified tolerance for flow adjustment. Note that (as typical of all HVAC equipment) there is a broad range of implementation for specific instrumentation devices.

Record Keeping

Balancing requires accurate record keeping while making field measurements. Dated and signed field test reports help the designer or customer in work approval, and the owner has a valuable reference when documenting future changes.

Sizing Balancing Valves and Flow Measurement Devices

Flow measurement devices and balancing valves are placed in the system to measure flow and, where required, adjust waterflow to a terminal, branch, zone, riser, or main. These should be located on the leaving side of the hydronic branch, following the temperature control valve and prior to isolation or service valves. General branch layout is from takeoff to entering service valve and strainer, then to the coil, control valve, and balancing/service valve. Pressure is thereby left on the coil, helping keep dissolved air in solution and preventing false balance problems resulting from collected air and improper pressure references.

An improper but commonly applied sizing method is to select the valve or device for line size. These devices should be selected to pass design flows when near or at their fully open position with the differential pressure required to accurately represent flow for the measurement range desired. Although a small pressure drop may allow determination of design flow, it should be remembered that measurements will almost always be taken at reduced flows. The square relationship between flow and head will greatly reduce the available differential pressure for measurement. If a minimum differential pressure of 1 psi is used for sizing, measurement at 50% design flow means measured ΔP will be 0.25 psi; conversely, twice the flow will be a drop of 4 psi. This factors into the practical and available instrumentation used in field measurement. If a manufacturer publishes a minimum accuracy of 0.072 psi 1 gpm with an uncorrected valve flow coefficient of 1, then a 1 psi drop would produce that reading at ±0.28 gpm, or ±30%. If the designer is specifying a flow tolerance of ±10%, then sizing of devices and matching them to instrumentation become very important. A bare minimum 1 psi pressure drop is suggested; more pressure drop for basic measurements is recommended. Many balancing valves and measuring meters give an accuracy of ±5% of range down to a pressure drop of 12 in. of water with the balancing valve wide open. Too large a balancing valve pressure drop affects the performance and flow characteristic of the control valve. Too small a pressure drop affects its flow measurement accuracy as it is closed to balance the system. Equation (5) may be used to determine the flow coefficient C_v for a balancing valve or to size a control valve.

The flow coefficient C_v is defined as the number of gallons of water per minute that flows through a wide-open valve with a pressure drop of 1 psi at 60°F. This is shown as

$$Q = C_v \sqrt{\frac{\Delta P}{\text{SG}}} \tag{4}$$

where

Q	=	design flow for terminal or valve, gpm
SG	=	specific gravity of fluid
ΔP	=	pressure drop, psi

If pressure drop is determined in feet of water Δh, Equation (5) can be shown as:

$$C_v = 1.5Q\sqrt{s_f/\Delta h} \tag{5}$$

where Δh is pressure drop in ft of water.

7. HYDRONIC BALANCING METHODS

Various techniques are used to balance hydronic systems. Balance by temperature difference and water balance by proportional method are the most common.

Preparation. Minimally, preparation before balancing should include collecting the following:

1. Pump submittal data; pump curves, motor data, etc.
2. Starter sizes and overload protection information
3. Control valve C_v ratings and temperature control diagrams
4. Chiller, boiler, and heat exchanger information; flow and head loss
5. Terminal unit information; flow and head loss data
6. Pressure relief and reducing valve setting
7. Flowmeter calibration curves
8. Other pertinent data

System Preparation for Static System

1. Examine piping system: Identify main pipes, risers, branches and terminals on as-built drawings. Check that flows for all balancing devices are indicated on drawings before beginning work. Check that design flows for each riser

equal the sum of the design flows through the terminals.

2. Examine reducing valve
3. Examine pressure relief valves
4. Examine expansion tank
5. For pumps, confirm
   - Location and size
   - Vented volute
   - Alignment
   - Grouting
   - Motor and lubrication
   - Nameplate data
   - Pump rotational direction
6. For strainers, confirm
   - Location and size
   - Mesh size and cleanliness
7. Confirm location and size of terminal units
8. Control valves:
   - Confirm location and size
   - Confirm port locations and flow direction
   - Set all valves open to coil
   - Confirm actuator has required force to close valve under loaded conditions
9. Ensure calibration of all measuring instruments, and that all calibration data are known for balancing devices
10. Remove all air from piping; all high points should have air vents

Pump Start-Up

1. Start pump and confirm rotational direction; if rotation is incorrect, have corrected.
2. Read differential head and apply to pump curve to observe flow approximates design.
3. Slowly close pump (if pump is under 25 hp) throttle valve to shutoff. Read pump differential head from gages.
   - If shutoff head corresponds with published curve, the previously prepared velocity head correction curve can be used as a pump flow calibration curve.
   - A significant difference between observed and published shutoff head can be caused by an unvented volute, a partially plugged impeller, or by an impeller size different from that specified.

Confirmation of System Venting

1. Confirm tank location and size.
2. Shut off pump; record shutoff gage pressure at tank junction.
3. Start pump and record operating pressure at tank junction.
4. Compare operating to shutoff pressures at tank junction. If there is no pressure change, the system is air-free.

5. Eliminate free air.
   - No air separation: Shut off pump and revent. Retest and revent until tank junction pressure is stable.
   - Air separation: Operate system until free air has been separated out, indicated by stable tank junction pressure.

Balancing

For single-, multiple-, and parallel pump systems, after pump start-up and confirmation of system venting,

1. Adjust pump throttle until pump head differential corresponds to design.
2. Record pump motor voltage and amperage, and pump strainer head, at design flow.
3. Balance equipment room piping circuit so that pumped flow remains constant over alternative flow paths.
4. Record chiller and boiler circuits (for multiple-pump systems, requires a flowmeter installed between header piping).

   For multiple-pump systems only,

5. Check for variable flow in source circuits when control valves are operated.
6. Confirm
   - Pump suction pressure remains above cavitations range for all operating conditions.
   - Pump flow rates remain constant.
   - Source working pressures are unaffected.

   For parallel-pump systems, follow steps (1) to (4), then shut off pumps alternately and

7. Record head differential and flow rate through operating pump, and operating pump motor voltage and current.
8. Confirm that operational point is satisfactory (no overload, cavitation potential, etc.).

Balance by Temperature Difference

This common balancing procedure is based on measuring the water temperature difference between supply and return at the terminal. The designer selects the cooling and/or heating terminal for a calculated design load at full-load conditions. At less than full load, which is true for most operating hours, the temperature drop is proportionately less. Figure 11 demonstrates this relationship for a heating system at a design Δt of 20°F for outdoor design of 10°F and room design of 70°F.

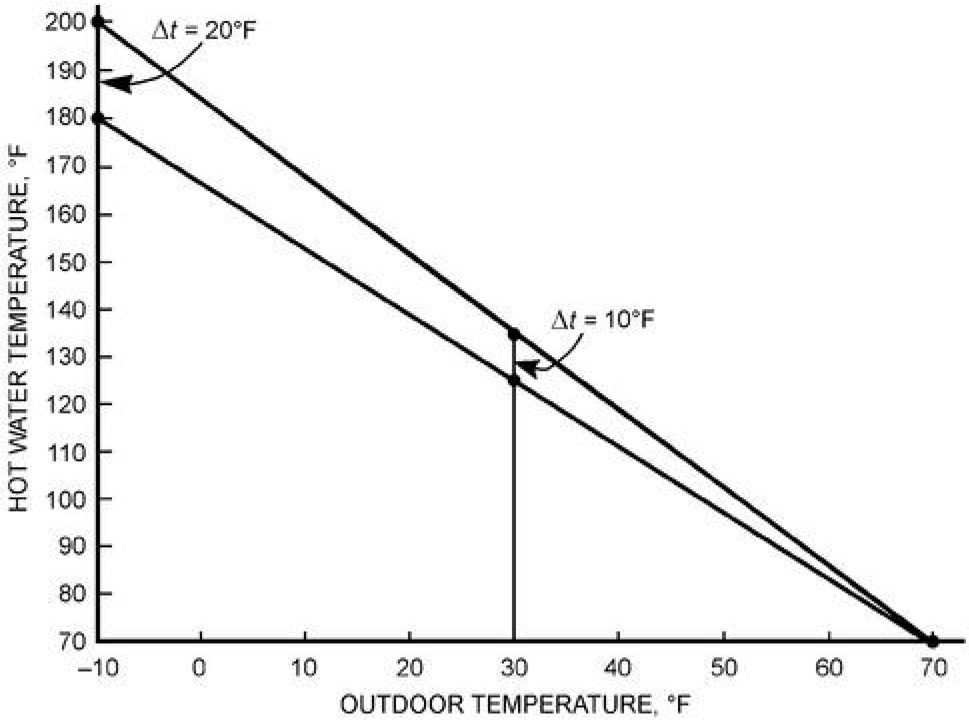

Figure 11. Water Temperature Versus Outdoor Temperature Showing Approximate Temperature Difference

For every outdoor temperature other than design, the balancing technician should construct a similar chart and read off the Δt for balancing. For example, at 50% load, or 30°F outdoor air, the Δt required is 10°F, or 50% of the design drop.

This method is a rough approximation and should not be used where great accuracy is required. It is not accurate enough for cooling systems.

Water Balance by Proportional Method

Preset Method. A thorough understanding of the pressure drops in the system riser piping, branches, coils, control valves, and balancing valves is needed. Generally, several pipe and valve sizes are available for designing systems with high or low pressure drops. A flow-limiting or trim device will be required. Knowing system pressure losses in design allows the designer to select a balancing device to absorb excess system pressures in the branch, and to shift pressure drop (which might be absorbed by a balancing device nearly close to achieve balance) to the pipes, coils, and valves so the balancing device merely trims these components' performance at design flow. It may also indicate where high-head-loss circuits can exist for either relocation in the piping network, or hydraulic isolation through hybrid piping techniques. The installed balancing device should never be closed more than 40 to 50%; below this point flow reading accuracy falls to 20 to 30%. Knowing a starting point for setting the valve (preset) allows the designer to iterate system piping design. This may not always be practical in large systems, but minimizing head and flow saves energy over the life of the facility and allows for proper temperature control. In this method,

1. Analyze the piping network for the largest hydraulic loss based on design flow and pipe friction loss. The pump should be selected to provide the total of all terminal flows, and the head required to move water through the hydraulically greatest circuit. Balance devices in this circuit should be sized only for the loss required for flow measurement accuracy. Trimming is not required.
2. Analyze differences in pressure drop in the pumping circuit for each terminal without using a balancing device. The difference between each circuit and the pump head (which represents the drop in the farthest circuit) is the required drop for the balancing device.
3. Select a balancing device that will achieve this drop with minimum valve throttling. If greater than two pipe sizes smaller, shift design drop into control valve or coil (or both), equalizing pressure drop across the devices.
4. Monitor system elevations and pressure drops to ensure air management, minimizing pocket collections and false pressure references that could lead to phantom balancing problems.
5. Use proportional balancing methods as outlined for field testing and adjustment.

Proportional Balancing

Proportional water-side balancing may use design data, but relies most on as-built conditions and measurements and adapts well to design diversity factors. This method works well with multiple-riser systems. When several terminals are connected to the same circuit, any variation of differential pressure at the circuit inlet affects flows in all other units in the same proportion. Circuits are proportionally balanced to each other by a flow quotient:

$$\text{Flow quotient} = \frac{\text{Actual flow rate}}{\text{Design flow rate}} \quad (6)$$

To balance a branch system proportionally,

1. Fully open the balancing and control valves in that circuit.
2. Adjust the main balancing valve for total pump flow of 100 to 110% of design flow.
3. Calculate each riser valve's quotient based on actual measurements. Record these values on the test form, and note the circuit with the lowest flow quotient.

Note: When all balancing devices are open, flow will be higher in some circuits than others. In some, flow may be so low that it cannot be accurately measured. The situation is complicated because an initial pressure drop in series with the pump is necessary to limit total flow to 100 to 110% of design; this decreases the available differential pressure for the distribution system. After all other risers are balanced, restart analysis of risers with unmeasurable flow at step (2).

Identify the riser with the highest flow ratio. Begin balancing with this riser, then continue to the next highest flow ratio, and so on. When selecting the branch with the highest flow ratio,

- Measure flow in all branches of the selected riser.
- In branches with flow higher than 150% of design, close the balancing valves to reduce flow to about 110% of design.
- Readjust total pump flow using the main valve.
- Start balancing in branches with a flow ratio greater than or equal to 1. Start with the branch with the highest flow ratio.

The reference circuit has the lowest quotient and the greatest pressure loss. Adjust all other balancing valves in that branch until they have the same quotient as the reference circuit (at least one valve in the branch should be fully open).

When a second valve is adjusted, the flow quotient in the reference valve also changes; continued adjustment is required to make their flow quotients equal. Once they are equal, they will remain equal or in proportional balance to each other while other valves in the branch are adjusted or until there is a change in pressure or flow.

When all balancing valves are adjusted to their branches' respective flow quotients, total system waterflow is adjusted to the design by setting the balancing valve at the pump discharge to a flow quotient of 1.

Pressure drop across the balancing valve at pump discharge is produced by the pump that is not required to provide design flow. This excess pressure can be removed by trimming the pump impeller or reducing pump speed. The pump discharge balancing valve must then be reopened fully to provide the design flow.

As in variable-speed pumping, diversity and flow changes are well accommodated by a system that has been proportionately balanced. Because the balancing valves have been balanced to each other at a particular flow (design), any changes in flow are proportionately distributed.

Balancing the water side in a system that uses diversity must be done at full flow. Because components are selected based on heat transfer at full flow, they must be balanced to this point. To accomplish full-flow proportional balance, shut off part of the system while balancing the remaining sections. When a section has been balanced, shut it off and open the section that was open originally to complete full balance of the system. When balancing, care should be taken if the building is occupied or if load is nearly full.

Variable-Speed Pumping. To achieve hydronic balance, full flow through the system is required during balancing, after which the system can be placed on automatic control and the pump speed allowed to change. After the full-flow condition is balanced and the system differential pressure set point is established, to control the variable-speed pumps, observe the flow on the circuit with the greatest resistance as the other circuits are closed one at a time. The flow in the observed circuit should remain equal to, or more than, the previously set flow. Waterflow may become laminar at less than 2 fps, which may alter the heat transfer characteristics of the system.

Other Balancing Techniques

Flow Balancing by Rated Differential Procedure. This procedure depends on deriving a performance curve for the test coil, comparing water temperature difference Δt_w to entering water temperature t_{ew} minus entering air temperature t_{ea}. One point of the desired curve can be determined from manufacturer's ratings, which are published as (t_{ew} − t_{ea}). A second point is established by observing that the heat transfer from air to water is zero when (t_{ew} − t_{ea}) is zero (consequently, Δt_w = 0). With these two points, an approximate performance curve can be drawn (Figure 12). Then, for any other (t_{ew} − t_{ea}), this curve is used to determine the appropriate Δt_w. The basic curve applies to catalog ratings for lower dry-bulb temperatures, providing consistent entering air moisture content (e.g., 75°F db, 65°F wb). Changes in inlet water temperature, temperature rise, air velocity, and dry- and wet-bulb temperatures cause terminal performance to deviate from the curves. The curve may also be used for cooling coils for sensible transfer (dry coil).

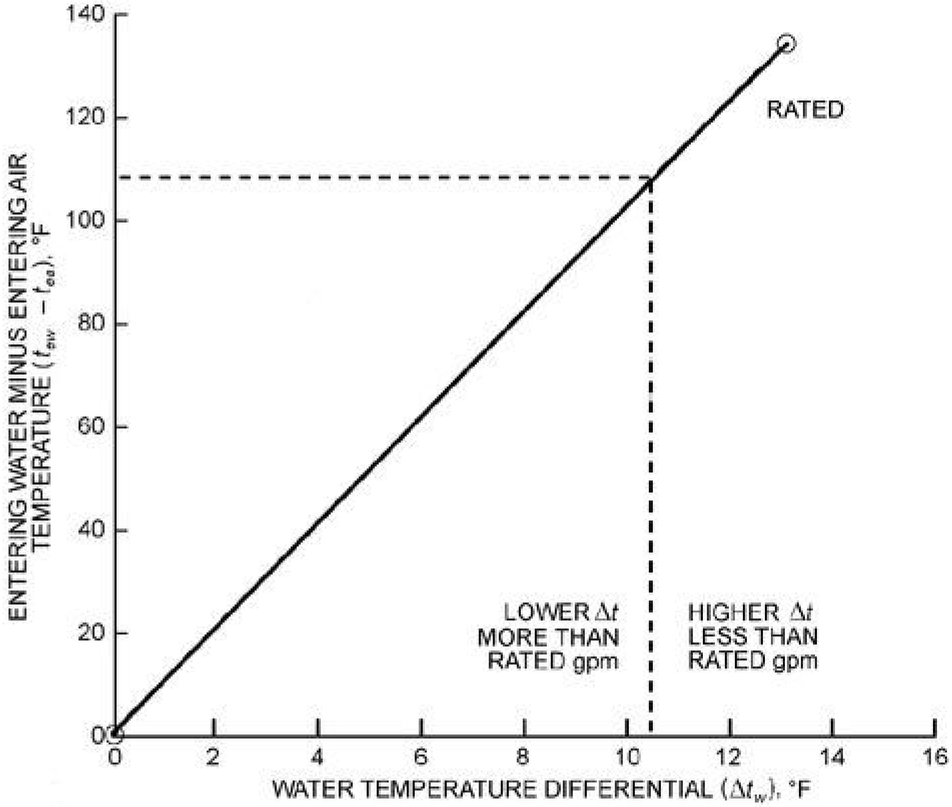

Figure 12. Coil Performance Curve

Flow Balancing by Total Heat Transfer. This procedure determines waterflow by running an energy balance around the coil. From field measurements of airflow, wet- and dry-bulb temperatures up- and downstream of the coil, and the difference Δt_w between entering and leaving water temperatures, waterflow can be determined by the following equations:

$$Q_w = q/500\Delta t_w \quad (7)$$

$$q_{cooling} = 4.5Q_a(h_1 - h_2) \quad (8)$$

$$q_{heating} = 1.08Q_a(t_1 - t_2) \quad (9)$$

where

Q_w	=	waterflow rate, gpm
q	=	load, Btu/h
$q_{cooling}$	=	cooling load, Btu/h
$q_{heating}$	=	heating load, Btu/h
Q_a	=	airflow rate, cfm
h	=	enthalpy, Btu/lb
t	=	temperature, °F

Example 1. Find the waterflow for a cooling system with the following characteristics:

Test data

t_{ewb}	=	entering wet-bulb temperature = 68.5°F
t_{lwb}	=	leaving wet-bulb temperature = 53.5°F
Q_a	=	airflow rate = 22,000 cfm

t_{lw} = leaving water temperature = 59.0°F
t_{ew} = entering water temperature = 47.5°F

From psychrometric chart
h_1 = 32.84 Btu/lb
h_2 = 22.32 Btu/lb

Solution: From Equations (5) and (6),

$$Q_w = \frac{4.5 \times 22{,}000(32.84 - 22.32)}{500(59.0 - 47.5)} = 181 \text{ gpm}$$

The desired waterflow is achieved by successive manual adjustments and recalculations. Note that these temperatures can be greatly influenced by the heat of compression, stratification, bypassing, and duct leakage.

General Balance Procedures

All the variations of balancing hydronic systems cannot be listed; however, the general method should balance the system and minimize operating cost. Excess pump pressure (operating power) can be eliminated by trimming the pump impeller. Allowing excess pressure to be absorbed by throttle valves adds a lifelong operating-cost penalty to the operation.

The following is a general procedure based on setting the balance valves on the site:

1. Develop a flow diagram if one is not included in the design drawings. Illustrate all balance instrumentation, and include any additional instrument requirements.
2. Compare pumps, primary heat exchangers, and specified terminal units, and determine whether a design diversity factor can be achieved.
3. Examine the control diagram and determine the control adjustments needed to obtain design flow conditions.

Balance Procedure: Primary and Secondary Circuits

1. Inspect the system completely to ensure that (1) it has been flushed out, it is clean, and all air is removed; (2) all manual valves are open or in operating position; (3) all automatic valves are in their proper positions and operative; and (4) the expansion tank is properly charged.
2. Place controls in position for design flow.
3. Examine flow diagram and piping for obvious short circuits; check flow and adjust the balance valve.
4. Take pump suction, discharge, and differential pressure readings at both full and no flow. For larger pumps, a no-flow condition may not be safe. In any event, valves should be closed slowly.
5. Read pump motor amperage and voltage, and determine approximate power.
6. Establish a pump curve, and determine approximate flow rate.
7. If a total flow station exists, determine the flow and compare with pump curve flow.
8. If possible, set total flow about 10% high using the total flow station first and the pump differential pressure second; then maintain pumped flow at a constant value as balance proceeds by adjusting the pump throttle valve.
9. Any branch main flow stations should be tested and set, starting by setting the shortest runs low as balancing proceeds to the longer branch runs.
10. With primary and secondary pumping circuits, a reasonable balance must be obtained in the primary loop before the secondary loop can be considered. The secondary pumps must be running and terminal units must be open to flow when the primary loop is being balanced, unless the secondary loop is decoupled.

8. FLUID FLOW MEASUREMENT

Flow Measurement Based on Manufacturer's Data

Any component (terminal, control valve, or chiller) that has an accurate, factory-certified flow/pressure drop relationship can be used as a flow-indicating device. The flow and pressure drop may be used to establish an equivalent flow coefficient as shown in Equation (3). According to the Bernoulli equation, pressure drop varies as the square of the velocity or flow rate, assuming density is constant:

$$Q_1^2/Q_2^2 = \Delta h_1/\Delta h_2 \tag{10}$$

For example, a chiller has a certified pressure drop of 25 ft of water at 100 gpm. The calculated flow with a field-measured pressure drop of 30 ft is

$$Q_2 = 100\sqrt{30/25} = 109.5 \text{ gpm} \tag{11}$$

Flow calculated in this manner is only an estimate. The accuracy of components used as flow indicators depends on the accuracy of (1) cataloged information concerning flow/pressure drop relationships and (2) pressure differential readings. As a rule, the component should be factory-certified flow tested if it is to be used as a flow indicator.

Pressure Differential Readout

Gages or digital differential pressure manometers are used to read differential pressures. Accurate readout is diminished when two separate devices are used, especially when the two are gages that are permanently mounted. When applying a single pressure gage for differential readout, follow the example of Figure 13. This gage should be alternately valved to the high- and low-pressure side to establish the differential. A single gage needs no static height correction, and excess coordinated errors caused by disparate gage calibration are eliminated.

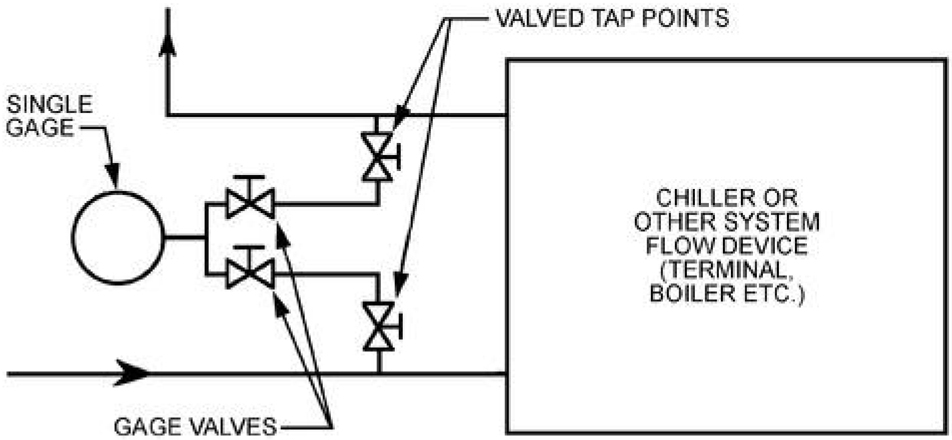

Figure 13. Single Gage for Reading Differential Pressure

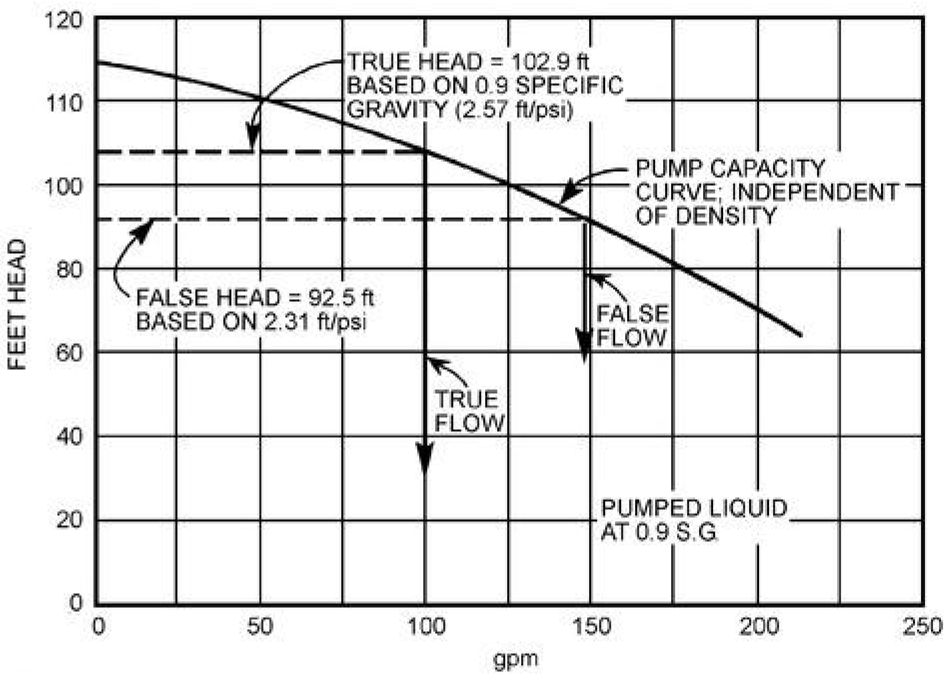

Figure 14. Fluid Density Correction Chart for Pump Curves

Differential pressure can also be read from differential gages, thus eliminating the need to subtract outlet from inlet pressures to establish differential pressure. Differential pressure gages are usually dual gages mechanically linked to read differential pressure. The differential pressure gage readout can be stated in terms of psi or in feet of head of 60°F water.

Conversion of Differential Pressure to Head

Pressure gage readings can be restated to fluid head, which is a function of fluid density. The common hydronic system conversion factor is related to water density at about 60°F; 1 psi equals 2.31 ft. Pressure gages can be calibrated to feet of water head using this conversion. Because the calibration only applies to water at 60°F, the readout may require correction when the gage is applied to water at a significantly higher temperature.

Pressure gage conversion and correction factors for various fluid specific gravities (in relation to water at 60°F) are shown in Table 2. The differential gage readout should only be defined in terms of the head of the fluid actually causing the flow pressure differential. When this is done, the resultant fluid head can be applied to the C_v to determine actual flow through any flow device, provided the manufacturer has correctly stated the flow to fluid head relationship.

For example, a manufacturer may test a boiler or control valve with 100°F water. If the test differential pressure is converted to head at 100°F, a C_v independent of test temperature and density may be calculated. Differential pressures from another test made in the field at 250°F may be converted to head at 250°F. The C_v calculated with this head is also independent of temperature. The manufacturer’s data can then be directly correlated with the field test to establish flow rate at 250°F.

A density correction must be made to the gage reading when differential heads are used to estimate pump flows as in Figure 14. This is because of the shape of the pump curve. An incorrect head difference entry into the curve caused by an uncorrected gage reading can cause a major error in the estimated pumped flow. In this case, the gage reading for a pumped liquid that has a specific gravity of 0.9 (2.57 ft liquid/psi) was not corrected; the gage conversion is assumed to be 2.31 ft liquid/psi. A 50% error in flow estimation is shown.

Differential Head Readout with Manometers

Manometers are used for differential pressure readout, especially when very low differentials, great precision, or both, are required. But manometers must be handled with care; they should not be used for field testing because fluid could blow out into the water and rapidly deteriorate the components. A proposed manometer arrangement is shown in Figure 15.

Figure 15 and the following instructions provide accurate manometer readings with minimum risk of blowout.

1. Make sure that both legs of manometer are filled with water.
2. Open purge bypass valve.
3. Open valved connections to high and low pressure.
4. Open bypass vent valve slowly and purge air here.
5. Open manometer block vents and purge air at each point.
6. Close needle valves. The columns should zero in if the manometer is free of air. If not, vent again.
7. Open needle valves and begin throttling purge bypass valve slowly, watching the fluid columns. If the manometer has an adequate available fluid column, the valve can be closed and the differential reading taken. However, if the fluid column reaches the top of the manometer before the valve is completely closed, insufficient manometer height is indicated and further throttling will blow fluid into the blowout collector. A longer manometer or the single gage readout method should then be used.

An error is often introduced when converting inches of gage fluid to feet of test fluid. The conversion factor changes with test fluid temperature, density, or both. Conversion factors shown in Table 2 are to a water base, and the counterbalancing water height *H* (Figure 15) is at room temperature.

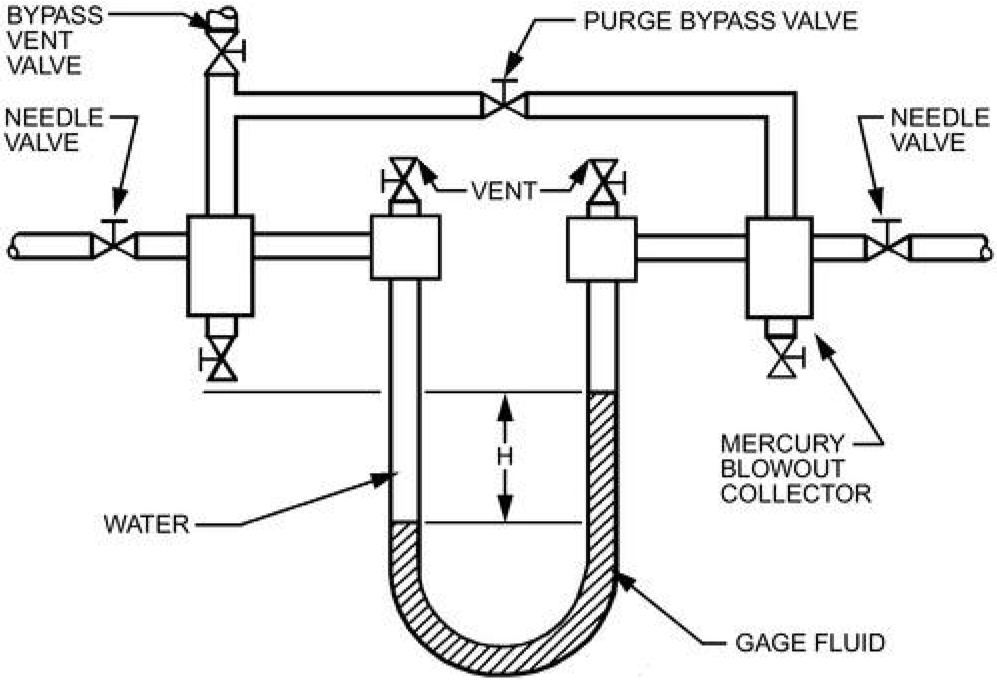

Figure 15. Fluid Manometer Arrangement for Accurate Reading and Blowout Protection

Table 2 Differential Pressure Conversion to Head

Fluid Specific Gravity	Corresponding Water Temperature, °F	Foot Fluid Head Equal to 1 psi[a]	Correction Factor When Gage is Stated to Feet of Water (60°F)[b]
1.5		1.54	
1.4		1.65	
1.3		1.78	
1.2		1.93	
1.1		2.10	
1.0	60	2.31	1.00
0.98	150	2.36	1.02
0.96	200	2.41	1.04
0.94	250	2.46	1.065
0.92	300	2.51	1.09
0.90	340	2.57	1.11
0.80		2.89	
0.70		3.30	
0.60		3.85	
0.50		4.63	

[a] Differential psi readout is multiplied by this number to obtain feet fluid head when gage is calibrated in psi.

[b] Differential feet water head readout is multiplied by this number to obtain feet fluid head when gage calibration is stated to feet head of 60°F water.

Orifice Plates, Venturi, and Flow Indicators

Manufacturers provide flow information for several devices used in hydronic system balance. In general, the devices can be classified as (1) orifice flowmeters, (2) venturi flowmeters, (3) velocity impact meters, (4) pitot-tube flowmeters, (5) bypass spring impact flowmeters, (6) calibrated balance valves, (7) turbine flowmeters, and (8) ultrasonic flowmeters.

The **orifice flowmeter** is widely used and is extremely accurate. The meter is calibrated and shows differential pressure versus flow. Accuracy generally increases as the pressure differential across the meter increases. The differential pressure readout instrument may be a manometer, differential gage, or single gage.

The **venturi flowmeter** has lower pressure loss than the orifice plate meter because a carefully formed flow path increases velocity head recovery. The venturi flowmeter is placed in a main flow line where it can be read continuously.

Velocity impact meters have precise construction and calibration. The meters are generally made of specially contoured glass or plastic, which allows observation of a flow float. As flow increases, the flow float rises in the calibrated tube to indicate flow rate. Velocity impact meters generally have high accuracy.

A special version of the velocity impact meter is applied to hydronic systems. This version operates on the velocity head difference between the pipe side wall and the pipe center, which causes fluid to flow through a small flowmeter. Accuracy depends on the location of the impact tube and on a velocity profile that corresponds to theory and the laboratory test calibration base. Generally, the accuracy of this **bypass flow impact** or differential velocity head flowmeter is less than a flow-through meter, which can operate without creating a pressure loss in the hydronic system.

The **pitot-tube flowmeter** is also used for pipe flow measurement. Manometers are generally used to measure velocity head differences because these differences are low.

The **bypass spring impact flowmeter** uses a defined piping pressure drop to cause a correlated bypass side branch flow. The side branch flow pushes against a spring that increases in length with increased flow. Each individual flowmeter is calibrated to relate extended spring length position to main flow. The bypass spring impact flowmeter has, as its principal merit, a direct readout. However, dirt on the spring reduces accuracy. The bypass is opened only when a reading is made. Flow readings can be taken at any time.

The **calibrated balance valve** is an adjustable orifice flowmeter. Balance valves can be calibrated so that a flow/pressure drop relationship can be obtained for each incremental setting of the valve. A ball, rotating plug, or butterfly valve may have its setting expressed in percent open or degree open; a globe valve, in percent open or number of turns. The calibrated balance valve must be manufactured with precision and care to ensure that each valve of a particular size has the same calibration characteristics.

The **turbine flowmeter** is a mechanical device. The velocity of the liquid spins a wheel in the meter, which generates a 4 to 20 mA output that may be calibrated in units of flow. The meter must be well maintained, because wear or water impurities on the bearing may slow the wheel, and debris may clog or break the wheel.

The **ultrasonic flowmeter** senses sound signals, which are calibrated in units of flow. The ultrasonic metering station may be installed as part of the piping, or it may be a strap-on meter. In either case, the meter has no moving parts to maintain, nor does it intrude into the pipe and cause a pressure drop. Two distinct types of ultrasonic meter are available: (1) the transit time meter for HVAC or clear-water systems and (2) the Doppler meter for systems handling sewage or large amounts of particulate matter.

If any of the above meters are to be useful, the minimum distance of straight pipe upstream and downstream, as recommended by the meter manufacturer and flow measurement handbooks, must be adhered to. Figure 16 presents minimum installation suggestions.

Using Pump as Indicator

Although the pump is not a meter, it can be used as an indicator of flow together with the other system components. Differential pressure readings across a pump can be correlated with the pump curve to establish the pump flow rate. Accuracy depends on (1) accuracy of readout, (2) pump curve shape, (3) actual conformance of the pump to its published curve, (4) pump operation without cavitation, (5) air-free operation, and (6) velocity head correction.

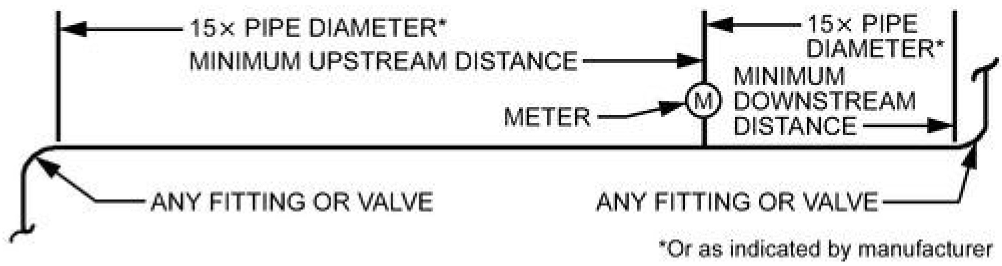

Figure 16. Minimum Installation Dimensions for Flowmeter

When a differential pressure reading must be taken, a single gage with manifold provides the greatest accuracy (Figure 17). The pump suction to discharge differential can be used to establish pump differential pressure and, consequently, pump flow rate. The single gage and manifold may also be used to check for strainer clogging by measuring the pressure differential across the strainer.

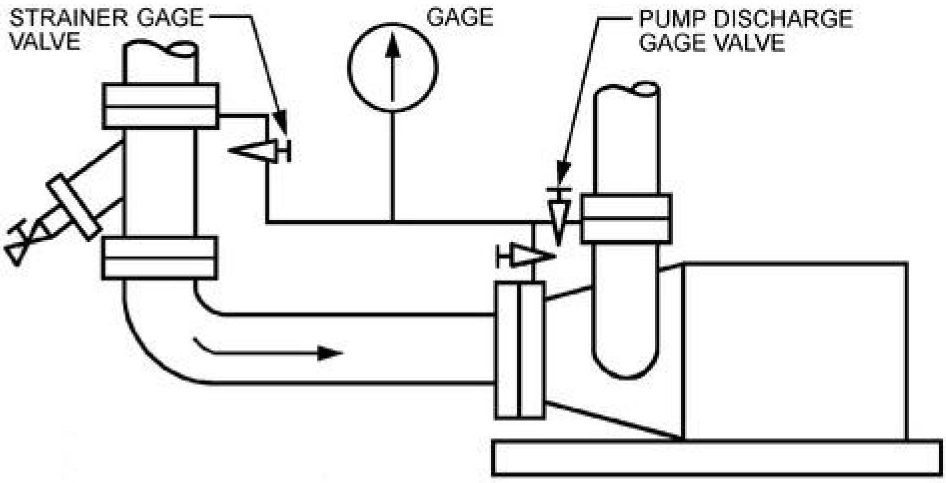

Figure 17. Single Gage for Differential Readout Across Pump and Strainer

If the pump curve is based on fluid head, pressure differential, as obtained from the gage reading, needs to be converted to head, which is pressure divided by the fluid weight per cubic foot. The pump differential head is then used to determine pump flow rate (Figure 18). As long as the differential head used to enter the pump curve is expressed as head of the fluid being pumped, the pump curve shown by the manufacturer should be used as described. The pump curve may state that it was defined by test with 85°F water. This is unimportant, because the same curve applies from 60 to 250°F water, or to any fluid within a broad viscosity range.

Generally, pump-derived flow information, as established by the performance curve, is questionable unless the following precautions are observed:

1. The installed pump should be factory calibrated by a test to establish the actual flow/pressure relationship for that particular pump. Production pumps can vary from the cataloged curve because of minor changes in impeller diameter, interior casting tolerances, and machine fits.
2. When a calibration curve is not available for a centrifugal pump being tested, the discharge valve can be closed briefly to establish the no-flow shutoff pressure, which can be compared to the published curve. If the shutoff pressure differs from that published, draw a new curve parallel to the published curve. Though not exact, the new curve usually fits the actual pumping circumstance more accurately. Clearance between the impeller and casing minimizes the danger of damage to the pump during a no-flow test, but manufacturer verification is necessary.
3. Differential head should be determined as accurately as possible, especially for pumps with flat flow curves.
4. The pump should be operating air-free and without cavitation. A cavitating pump will not operate to its curve, and differential readings will provide false results.
5. Ensure that the pump is operating above the minimum net positive suction head.
6. Power readings can be used (1) as a check for the operating point when the pump curve is flat or (2) as a reference check when there is suspicion that the pump is cavitating or providing false readings because of air.
7. The flow determined by the pump curve should be compared to the flow measured at the flowmeters, flow measured by pressure drops through circuits, and flow measured by pressure drops through exchangers.
8. The pump flow derived from the pressure differential at the suction and discharge connections is only an indicator of the actual flow; it cannot be used to verify the test and balance measurements. If pump flow is to be used for balancing verification, it needs to be determined using the Hydraulic Institute procedure or by measuring the flow through a properly installed metering station 15 to 20 straight pipe diameters downstream from the pump discharge.

Power draw should be measured in watts. Ampere readings cannot be trusted because of voltage and power factor problems. If motor efficiency is known, the wattage drawn can be related to pump brake power (as described on the pump curve) and the operating point determined.

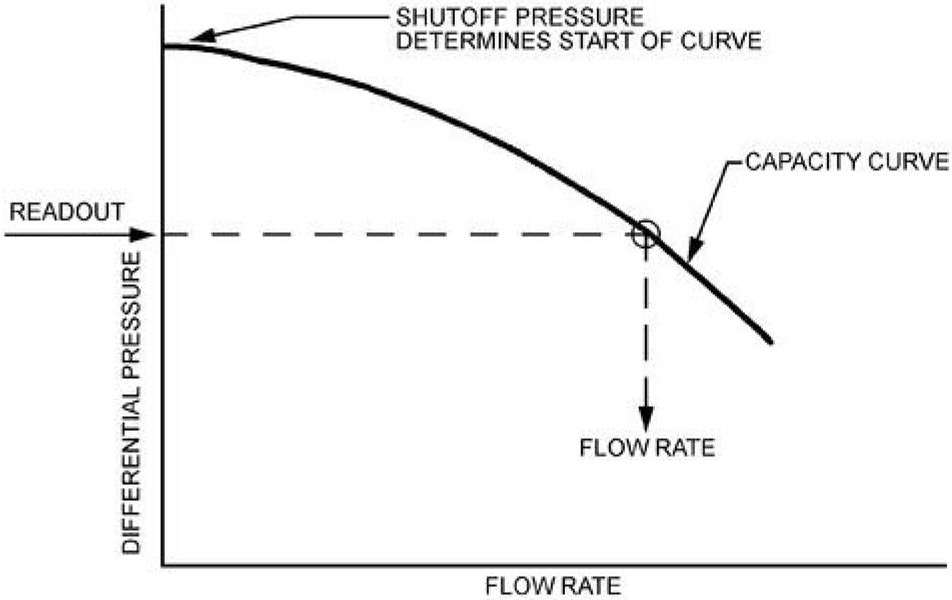

Figure 18. Differential Pressure Used to Determine Pump Flow

Table 3 Instruments for Monitoring a Water System

Point of Information	Manifold Gage	Single Gage	Thermometer	Test Well	Pressure Tap
Pump: Suction, discharge	x				
Strainer: In, out					x
Cooler: In, out		x	x		
Condensers: In, out		x	x		
Concentrator: In, out		x	x		
Absorber: In, out		x	x		
Tower cell: In, out				x	x
Heat exchanger: In, out	x		x		
Coil: In, out				x	x
Coil bank: In, out		x	x		
Booster coil: In, out					x
Cool panel: In, out					x
Heat panel: In, out				x	x
Unit heater: In, out					x
Induction: In, out					x
Fan-coil: In, out					x
Water boiler: In, out			x		
Three-way valve: All ports					x
Zone return main			x		
Bridge: In, out			x		
Water makeup		x			
Expansion tank		x			
Strainer pump					x
Strainer main	x				
Zone three-way: All ports				x	x

Central Plant Chilled-Water Systems

For existing installations, establishing accurate thermal load profiles is of prime importance because it establishes proper primary chilled-water supply temperature and flow. In new installations, actual load profiles can be compared with design load profiles to obtain valid operating data.

To perform proper testing and balancing, all interconnecting points between the primary and secondary systems must be designed with sufficient temperature, pressure, and flow connections so that adequate data may be indicated and/or recorded.

Water Flow Instruments

As indicated previously, proper location and use of instruments is vital to accurate balancing. Instruments for testing temperature and pressure at various locations are listed in Table 3. Flow-indicating devices should be placed in water systems as follows:

- At each major heating coil bank (10 gpm or more)
- At each major cooling coil bank (10 gpm or more)
- At each bridge in primary-secondary systems
- At each main pumping station
- At each water chiller evaporator
- At each water chiller condenser
- At each water boiler outlet
- At each floor takeoff to booster reheat coils, fan coil units, induction units, ceiling panels, and radiation (do not exceed 25 terminals off of any one zone meter probe)
- At each vertical riser to fan coil units, induction units, and radiation
- At the point of tie-in to existing systems

9. BALANCING STEAM DISTRIBUTION SYSTEMS

Procedures for Steam Balancing Variable Flow Systems

Steam distribution cannot be balanced by adjustable flow-regulating devices. Instead, fixed restrictions built into the piping in accordance with carefully designed pipe and orifice sizes are used to regulate flow.

It is important to have a balanced distribution of steam to all portions of the steam piping at all loads. This is best accomplished by properly designing the steam distribution piping, which includes carefully considering steam pressure, steam quantities required by each branch circuit, pressure drops, steam velocities, and pipe sizes. Just as other flow systems are balanced, steam distribution systems are balanced by ensuring that the pressure drops are equalized at design flow rates for all portions of the piping. Only marginal balancing can be done by pipe sizing. Therefore, additional steps must be taken to achieve a balanced performance.

Steam flow balance can be improved by using spring-type packless supply valves equipped with precalibrated orifices. The valves should have a tight shutoff between 25 in. of Hg and 60 psig. These valves have a nonrising stem, are available with a lockshield, and have a replaceable disk. Orifice flanges can also be used to regulate and measure steam flow at appropriate locations throughout the system. The orifice sizes are determined by the pressure drop required for a given flow rate at a given location. A schedule should be prepared showing (1) orifice sizes, (2) valve or pipe sizes, (3) required flow rates, and (4) corresponding pressure differentials for each flow rate. It may be useful to calculate pressure differentials for several flow rates for each orifice size. Such a schedule should be maintained for future reference.

After the appropriate regulating orifices are installed in the proper locations, the system should be tested for tightness by sealing all openings in the system and applying a vacuum of 20 in. of Hg, held for 2 hours. Next, the system should be readied for warm-up and pressurizing with steam following the procedures outlined in Section VI of the ASME *Boiler and Pressure Vessel Code*. After the initial warm-up and system pressurization, evaluate system steam flow, and compare it to system requirements. The orifice schedule calculated earlier will now be of value should any of the orifices need to be changed.

Steam Flow Measuring Devices

Many devices are available for measuring flow in steam piping: (1) steam meters, (2) condensate meters, (3) orifice plates, (4) venturi fittings, (5) steam recorders, and (6) manometers for reading differential pressures across orifice plates and venturi fittings. Some of these devices are permanently affixed to the piping system to facilitate taking instantaneous readings that may be necessary for proper operation and control. A surface pyrometer used in conjunction with a pressure gage is a convenient way to determine steam saturation temperature and the degree of superheat at various locations in the system. This information can be used to evaluate performance characteristics.

Steam Pressure Regulation

Many large steam systems generate steam at higher pressures (for distribution efficiencies) than what is required by the building systems, and then modulate the pressure using pressure-reducing valves (PRVs). To aid in stable pressure control at low loads, many engineers install two PRVs sized for 1/3 and 2/3 of the design flow rate. To aid in stable pressure control during moderate loads, verify that the 2/3 PRV does not open until the 1/3 PRV is full open.

10. BALANCING COOLING TOWERS

Field-testing cooling towers is demanding and difficult. ASME *Standard* PTC 23 and CTI *Standard Specification* ATC-105 establish procedures for these tests. Certain general guidelines for testing cooling towers are as follows.

Waterflow from condenser to cooling tower should be the same flow. There may be basins and bypasses in the path that affect this pattern. Flow measurements should be made at both locations. For accurate flow measurements and good quality of flow, meters are required to be installed in the supply piping to each cooling tower and to each condenser. The condenser supply is from the cooling tower. This is a requirement even if there is more than one chiller or more than one cooling tower per system.

Measurements and Verification Process

1. Measure waterflow both into and out of the condenser.
2. Measure waterflow in the cooling tower and balance each cooling tower for design flow.
3. Measure flow of makeup water to each tower basin. Set overflow to zero during test so the evaporation rate can be determined. During test, isolate make up water.
4. Verify control valves are operating properly.
5. Verify the entire condenser water system is operating correctly by allowing the system to go to full cooling. Not all chillers need to run with adequate flow meters, but the controls must allow full flow through the condenser and cooling tower. Take final flow measurements and record for the final report.
6. Measure and record the temperatures on and off the cooling towers.
7. Measure and record outdoor wet-bulb temperature.
8. If the cooling tower has nozzles and pressure gages installed, take pressure measurements on each line to the nozzles at full flow and record.
9. Measure power usage including nameplate data. Include motor amperage, voltage, rpm, safety factor, overload protection, manufacturer, and rating. List nameplate motor power and actual boiler horsepower.
10. List cooling tower airflow from boiler horsepower and manufacturers' data.

Calculations and Verification

1. Calculate heat rejection of cooling tower as follows.

$$\text{Flow} \times \Delta t \times \text{factor/rate} = \text{heat rejection tons}$$

   Example:

$$1000 \text{ gpm} \times 20\ \Delta t\ ^\circ\text{F} \times 500/15{,}000 \text{ tons} = 667 \text{ heat rejection tons}$$

2. Verify and record data that each cooling tower is operating within manufacturers' design. Verify
   - Waterflow
   - Airflow
   - Power

- Makeup water
- Overflow water
- Water treatment (with data from water treatment contractor)

3. If standby cooling towers and equipment are in the system, start up the standby units and shut down the tested units and repeat test.

11. VERIFICATION OF CONTROLS OPERATION

The performance of the HVAC system's automatic controls should be inspected and tested in each seasonal mode. In addition, the performance of all life safety devices and their interface with the HVAC systems should be verified and reported. In general, the TAB technician is responsible for verifying that the control system is operating as specified, and for reporting any installation problems discovered. Basically, this means (1) setting controls to a proper fixed mode to prevent changes during balancing, and (2) verifying proper operation. Actual adjusting, moving, or recalibrating controls is normally the responsibility of the control contractor. However, TAB technicians should work closely with the control contractor to ensure system operation within design limitations, identify and correct any problems, and ensure the safety of the system and its components, fulfilling the following steps:

1. Verify that controllers, including limiting controllers (e.g., fire stats and freeze stats), are calibrated and in control.
2. Verify that controller set points meet design intent.
3. Confirm that the sequences of operation for any control mode are in compliance with the approved drawings.
4. Check that the control terminations are in accordance with the approved drawings.
5. Verify the settings, operation, and adjustment of all end switches, mercury switches, solenoid valves, contractors, etc.
6. Check the operation of lockout or interlock systems.
7. Check the operation of all valve and damper actuators.
8. Determine that all controlled devices are properly connected.
9. Verify the operation of pilot positioners.
10. Confirm that all controlled devices are operated by the intended controller and note any overlap of controlled devices.
11. Prove that all controlled devices are in the position indicated by the controller (either open, closed, or modulating).
12. Determine the integrity of all controlled devices with regard to tightness of close-off and full-open positions. This includes dampers in multizone units, mixing boxes, and VAV air terminal devices.
13. Ensure that all controlled devices have free travel.
14. Verify that all controlled devices are properly installed in the distribution system with respect to direction of flow and location.
15. Confirm the proper operation of all controlled devices as applicable to normally open or normally closed.
16. Test the fail-safe modes of all controlled devices.
17. Examine the span of controls from a normally open position to a normally closed position, observing any dead bands, excessive pressures, and leading or lagging of simultaneously or sequentially controlled devices.
18. Check the location and installation of all sensors to determine if they will sense only the intended temperatures, humidities, or pressures.
19. Also check for potential erratic operation because of outdoor influences such as sunlight, drafts, outdoor walls, etc.

For pneumatic systems:

1. Check main supply air for proper pressures.

2. Observe the operation of the compressor and dryer.

For electronic systems:

1. Confirm that the control voltage is correct.
2. With the system in normal operation, test each control loop at both ends of its control range to verify that all control loops and their individual field points are responding correctly.
3. Check the calibration of all field sensors.
4. Verify the calibration and response time of all transducers.
5. Determine if the system has lightning protection and battery back-up.

For direct digital systems:

1. Confirm that the control voltage is correct.
2. With the system in normal operation, test each control loop at both ends of its control range to prove that all control loops and their individual field points are responding correctly.
3. Check the calibration of all field sensors.
4. Verify the calibration and response time of all transducers.
5. Determine if the system has lightning protection and battery back-up.
6. Confirm the application and accuracy of the software algorithms for each control loop.
7. Test the operation of the phone modem.

12. THERMAL PERFORMANCE VERIFICATION

After performing all preceding procedures, the system shall be set to simulate design conditions. Measure and record a complete set of dry-bulb and wet-bulb temperatures for air entering and leaving coils and heat exchangers, air leaving terminal devices (diffusers), and air in conditioned rooms or spaces. If conditions cannot be simulated and this affects verification, it should be documented in the testing and balancing report.

13. OUTDOOR AIR VENTILATION VERIFICATION

After completion of the balancing procedures, the system outdoor air rate should be verified. This is necessary to ensure that the design minimum outdoor air is being supplied to the occupied spaces. Obtain the minimum outdoor air rate and the appropriate balance conditions from the design documents. Determine the total system actual flow rate by traverse or other approved method and the return air rate by the same method. If adequate space is not available to perform a proper traverse, use the temperature ratio method if the outdoor temperature is at least 20°F above or below the return air temperature. Adjust the outdoor air rate to equal the required flow rate by balancing the return air system to allow sufficient outdoor air to enter the system. This setting should be locked in and marked as the minimum outdoor air setting. After setting the outdoor air rate, recheck the total system flow to make sure that it has not changed.

14. TEMPERATURE CONTROL VERIFICATION

The test and balance technician should work closely with the temperature control installer to ensure that the project is completed correctly. The balancing technician needs to verify proper operation of the control and communicate findings back to the agency responsible for ensuring that the controls have been installed correctly. This is usually the HVAC system designer, although others may be involved. Generally, the balancing technician does not adjust, relocate, or calibrate the controls. However, this is not always the case, and differences do occur with VAV terminal unit controllers. The balancing technician should be familiar with the specifications and design intent of the project so that all responsibilities are understood.

During the design and specification phase of the project, the designer should specify verification procedures for the controls and responsibilities for the contractor who installs the temperature controls. It is important that the designer specify the (1) degree of coordination between the installer of the control and the balancing technician and (2) testing responsibilities of each.

Verification of control operation starts with the balancing technician reviewing the submitted documents and shop drawings of the control system. In some cases, the controls technician should instruct the balancing technician in the operation of certain control elements, such as digital terminal unit controllers. This is followed by schedule coordination between the control and balancing technicians. In addition, the balancing and controls technicians need to work together when reviewing the operation of some sections of the HVAC system, particularly with VAV systems and the setting of the flow measurement parameters in digital terminal unit controllers.

Major mechanical systems should be verified after testing, adjusting, and balancing is completed. The control system should be operated in stages to prove it can match system capacity to varying load conditions. Mechanical subsystem controllers should be verified when balancing data are collected, considering that the entire system may not be completely functional at the time of verification. Testing and verification should account for seasonal variations; tests should be performed under varying outdoor loads to ensure operational performance. Retesting a random sample of terminal units may be desirable to verify the control technician’s work.

Suggested Procedures

The following verification procedures may be used with either pneumatic or electrical controls:

1. Obtain design drawings and documentation, and become well acquainted with the design intent and specified responsibilities.
2. Obtain copies of approved control shop drawings.
3. Compare design to installed field equipment.
4. Obtain recommended operating and test procedures from manufacturers.
5. Verify with the control contractor that all controllers are calibrated and commissioned.
6. Check location of transmitters and controllers. Note adverse conditions that would affect control, and suggest relocation as necessary.
7. Note settings on controllers. Note discrepancies between set point for controller and actual measured variable.
8. Verify operation of all limiting controllers, positioners, and relays (e.g., high- and low-temperature thermostats, high- and low-differential pressure switches, etc.).
9. Activate controlled devices, checking for free travel and proper operation of stroke for both dampers and valves. Verify normally open (NO) or normally closed (NC) operation.
10. Verify sequence of operation of controlled devices. Note line pressures and controlled device positions. Correlate to air or waterflow measurements. Note speed of response to step change.
11. Confirm interaction of electrically operated switch transducers.
12. Confirm interaction of interlock and lockout systems.
13. Coordinate balancing and control technicians’ schedules to avoid duplication of work and testing errors.

Pneumatic System Modifications

1. Verify main control supply air pressure and observe compressor and dryer operation.
2. For hybrid systems using electronic transducers for pneumatic actuation, modify procedures accordingly.

Electronic Systems Modifications

1. Monitor voltages of power supply and controller output. Determine whether the system operates on a grounded or nongrounded power supply, and check condition. Although electronic controls now have more robust electronic circuits, improper grounding can cause functional variation in controller and actuator performance from system to system.
2. Note operation of electric actuators using spring return. Generally, actuators should be under control and use springs only upon power failure to return to a fail-safe position.

Direct Digital Controllers

Direct digital control (DDC) offers nontraditional challenges to the balancing technician. Many control devices, such as sensors and actuators, are the same as those in electronic and pneumatic systems. Currently DDC is dominated by two types of controllers: fully programmable or application-specific. Fully programmable controllers offer a group of functions linked together in an applications program to control a system such as an air-handling unit. Application-specific controllers are functionally defined with the programming necessary to carry out the functions required for a system, but not all adjustments and settings are defined. Both types of controllers and their functions have some variations. One of the functions is adaptive control, which includes control algorithms that automatically adjust settings of various controller functions.

The balancing technician must understand controller functions so that they do not interfere with the test and balance functions. Literacy in computer programming is not necessary, although it does help. When testing the DDC,

1. Obtain controller application program. Discuss application of the designer's sequence with the control programmer.
2. Coordinate testing and adjustment of controlled systems with mechanical systems testing. Avoid duplication of efforts between technicians.
3. Coordinate storage (e.g., saving to central DDC database and controller memory) of all required system adjustments with control technician.

In cases where the balancing agency is required to test discrete points in the control system,

1. Establish criteria for test with the designer.
2. Use reference standards that test the end device through the entire controller chain (e.g., device, wiring, controller, communications, and operator monitoring device). An example would be using a dry block temperature calibrator (a testing device that allows a temperature to be set, monitored, and maintained in a small chamber) to test a space temperature sensor. The sensor is installed with extra wire so that it may be removed from the wall and placed in the calibrator chamber. After the system is thermally stabilized, the temperature is read at the controller and the central monitor, if installed.
3. Report findings of reference and all points of reading.

Refer to ASHRAE *Standard* 111 for further details on HVAC TAB.

15. TESTING FOR SOUND AND VIBRATION

Testing for sound and vibration ensures that equipment is operating satisfactorily and that no objectionable noise and vibration are transmitted to the building structure and occupied space. Although sound and vibration are specialized fields that require expertise not normally developed by the HVAC engineer, the procedures to test HVAC are relatively simple and can be performed with a minimum of equipment by following the steps outlined in this section. Although this section provides useful information for resolving common noise and vibration problems, consult Chapter 49 for details on problem solving or the design of HVAC.

Testing for Sound

Present technology does not test whether equipment is operating within rated sound levels; field tests can only determine sound pressure levels, and equipment ratings are almost always in terms of sound power levels. Until new techniques are developed, the testing engineer can only determine (1) whether sound pressure levels are within desired limits and (2) which equipment, systems, or components are the source of excessive or disturbing transmission.

Sound-Measuring Instruments. Although an experienced listener can often determine whether systems are operating in an acceptably quiet manner, sound-measuring instruments are necessary to determine whether system noise levels are in compliance with specified criteria, and if not, to obtain and report detailed information to evaluate the cause of noncompliance. Instruments normally used in field testing are as follows.

The **precision sound level meter** is used to measure sound pressure level. The most basic sound level meters measure overall sound pressure level and have up to three weighted scales that provide limited filtering capability. The instrument is useful in assessing outdoor noise levels in certain situations and can provide limited information on the low-frequency content of overall noise levels, but it provides insufficient information for problem diagnosis and solution. Its usefulness in evaluating indoor HVAC sound sources is thus limited.

Proper evaluation of HVAC sound sources requires a sound level meter capable of filtering overall sound levels into frequency increments of one octave or less.

Sound analyzers provide detailed information about sound pressure levels at various frequencies through filtering networks. The most popular sound analyzers are the octave band and one third octave band center frequency analyzers, which break the sound into the eight octave bands or twenty-four third octave bands of audible sound. Octave band or narrower sound analyzers are required where specifications are based on noise criteria (NC) and room criteria (RC) curves or similar frequency criteria and for problem jobs where knowledge of frequency is necessary to determine proper corrective action.

Personal computers are a versatile sound-measuring tool. Software used on portable computers has all the functional capabilities described previously, plus many that previously required a fully equipped acoustical laboratory. This type of sound-measuring system is many times faster and much more versatile than conventional sound level meters. With suitable accessories, it can also be used to evaluate vibration levels. Accuracy and calibration to applicable standards are of concern for software.

Regardless of which sound-measuring system is used, it should be calibrated before each use. Some systems have built-in calibration, while others use external calibrators. Much information is available on the proper application and use of sound-measuring instruments.

Air noise, caused by air flowing at a velocity of over 1000 fpm or by winds over 12 mph, can cause substantial error in sound measurements because of wind effect on the microphone. For outdoor measurements or in drafty places, either a wind screen for the microphone or a special microphone is required. When in doubt, use a wind screen on standard microphones.

Sound Level Criteria. Without specified values, the testing engineer must determine whether sound levels are within acceptable limits (Table 1 in Chapter 49 Note that a complete absence of noise is seldom a design criterion, except for certain critical locations such as sound and recording studios. In most locations, a certain amount of noise is desirable to mask other noises and provide speech privacy; it also provides an acoustically pleasing environment, because few people can function effectively in extreme quiet. Table 1 in Chapter 8 of the 2021 *ASHRAE Handbook—Fundamentals* lists typical sound pressure levels. Most field sound-measuring instruments and techniques yield an accuracy of ±3 dB, the smallest difference in sound pressure level that the average person can discern. A reasonable tolerance for sound criteria is 5 dB.

The measured sound level of any location is a combination of all sound sources present, including sound generated by HVAC equipment, as well as sound from other sources such as plumbing systems and fixtures, elevators, light ballasts, and outdoor noises. In testing for sound, all sources from other than HVAC equipment are considered background or ambient noise.

Background sound measurements generally have to be made (1) when the specification requires that the sound levels from HVAC equipment only, as opposed to the sound level in a space, not exceed a certain specified level; (2) when the sound level in the space exceeds a desirable level, in which case the noise contributed by the HVAC system must be determined; and (3) in residential locations where little significant background noise is generated during the evening hours and where generally low allowable noise levels are specified or desired. Because background noise from outdoor sources such as vehicular traffic can fluctuate widely, sound measurements for residential locations are best made in the normally quiet evening hours. Procedures for residential sound measurements can be found in ASTM *Standard* E1574, Measurement of Sound in Residential Spaces.

Sound Testing. Ideally, a building should be completed and ready for occupancy before sound level tests are taken. All spaces in which readings will be taken should be furnished with whatever drapes, carpeting, and furniture are typical because these affect the room absorption, which can affect sound levels and the subjective quality of the sound. In actual practice, because most tests must be conducted before the space is completely finished and furnished for final occupancy, the testing engineer must make some allowances. Because furnishings increase the absorption coefficient and reduce by about 4 dB the sound pressure level that can be expected between most live and dead spaces, the following guidelines should suffice for measurements made in unfurnished spaces. If the sound pressure level is 5 dB or more over the specified or desired criterion, it can be assumed that the criterion will not be met, even with the increased absorption provided by furnishings. If the sound pressure level is under 4 dB greater than the specified or desired criterion, recheck when the room is furnished to determine compliance.

Follow this general procedure:

1. Obtain a complete set of accurate, as-built drawings and specifications, including duct and piping details. Review specifications to determine sound and vibration criteria and any special instructions for testing.

2. Visually check for noncompliance with plans and specifications, obvious errors, and poor workmanship. Turn system on for aural check. Listen for noise and vibration (especially duct leaks and loose fittings).

3. Adjust and balance equipment, as described in other sections, so that final acoustical tests are made with the HVAC system operating as designed. It is desirable to perform acoustical tests for both summer and winter operation, but where this is not practical, make tests for the summer operating mode, as it usually has the potential for higher sound levels. Tests must be made for all mechanical equipment and systems, including standby.

4. Check calibration of instruments.

5. Measure sound levels in all areas as required, combining measurements if equipment or systems must be operated separately. Before final measurements are made in any particular area, survey the area using an A-weighted scale reading (dBA) to determine the location of the highest sound pressure level. Indicate this location on a testing form, and use it for test measurements. Restrict the preliminary survey to determine location of test measurements to areas that can be occupied by standing or sitting personnel. For example, measurements would not be made directly below a diffuser located in the ceiling, but would be made as close to the diffuser as standing or sitting personnel might be situated. In the absence of specified sound criteria, the testing engineer

should measure sound pressure levels in all occupied spaces to determine compliance with criteria indicated in Table 1 in Chapter 49 and to locate any sources of excessive or disturbing noise. With octave band sound level measurements, overall NC and RC values can be determined using measurements in the 125 Hz to 8000 Hz range.

6. Determine whether background noise measurements must be made.
   - If specification requires determining sound level from HVAC equipment only, background noise readings must be taken with HVAC equipment turned off.
   - If specification requires compliance with a specific noise level or criterion (e.g., sound levels in office areas not to exceed 35 dBA), ambient noise measurements must be made only if the noise level in any area exceeds the specified value.
   - For residential locations and areas requiring very low noise, such as sound recording studios and locations used during the normally quieter evening hours, it is usually desirable to take sound measurements in the evening and/or take ambient noise measurements.
7. For outdoor noise measurements to determine noise radiated by outdoor or roof-mounted equipment such as cooling towers and condensing units, the section on Sound Control for Outdoor Equipment in Chapter 49, which presents proper procedure and necessary calculations, should be consulted.

Noise Transmission Problems. Regardless of precautions taken by the specifying engineer and installing contractors, situations can occur where the sound level exceeds specified or desired levels, and there will be occasional complaints of noise in completed installations. A thorough understanding of Chapter 49 and the section on Testing for Vibration in this chapter is desirable before attempting to resolve any noise and vibration transmission problems. The following is intended as an overall guide rather than a detailed problem-solving procedure.

All noise transmission problems can be evaluated in terms of the source-path-receiver concept. Objectionable transmission can be resolved by (1) reducing noise at the source by replacing defective equipment, repairing improper operation, proper balancing and adjusting, and replacing with quieter equipment; (2) attenuating paths of transmission with silencers, vibration isolators, and wall treatment to increase transmission loss; and (3) reducing or masking objectionable noise at the receiver by increasing room absorption or introducing a nonobjectionable masking sound. The following discussion includes ways to identify actual noise sources using simple instruments or no instruments and possible corrections.

When troubleshooting in the field, the engineer should listen to the offending sound. The best instruments are no substitute for careful listening, because the human ear has the remarkable ability to identify certain familiar sounds such as bearing squeak or duct leaks and can discern small changes in frequency or sound character that might not be apparent from meter readings only. The ear is also a good direction and range finder; noise generally gets louder as one approaches the source, and direction can often be determined by turning the head. Hands can also identify noise sources. Air jets from duct leaks can often be felt, and the sound of rattling or vibrating panels or parts often changes or stops when these parts are touched.

In trying to locate noise sources and transmission paths, the engineer should consider the location of the affected area. In areas remote from equipment rooms containing significant noise producers but adjacent to shafts, noise is usually the result of structure-borne transmission through pipe and duct supports and anchors. In areas adjoining, above, or below equipment rooms, noise is usually caused by openings (acoustical leaks) in the separating floor or wall or by improper, ineffective, or maladjusted vibration isolation systems.

Unless the noise source or path of transmission is quite obvious, the best way to identify it is by eliminating all sources systematically as follows:

1. Turn off all equipment to make sure that the objectionable noise is caused by the HVAC. If the noise stops, the HVAC components (compressors, fans, and pumps) must be operated separately to determine which are contributing to the objectionable noise. Where one source of disturbing noise predominates, the test can be performed starting with all equipment in operation and turning off components or systems until the disturbing noise is eliminated. Tests can also be performed starting with all equipment turned off and operating various component equipment singularly, which permits evaluation of noise from each individual component.

   Any equipment can be termed a predominant noise source if, when the equipment is shut off, the sound level drops 3 dBA or if, when measurements are taken with equipment operating individually, the sound level is within 3 dBA of the overall objectionable measurement.

   When a sound level meter is not used, it is best to start with all equipment operating and shut off components one at a time because the ear can reliably detect differences and changes in noise but not absolute levels.
2. When some part of the HVAC system is established as the source of objectionable noise, try to further isolate the source. By walking around the room, determine whether the noise is coming through air outlets or returns, hung ceiling, or floors or walls.

3. If the noise is coming through the hung ceiling, check that ducts and pipes are isolated properly and not touching the hung ceiling supports or electrical fixtures, which would provide large noise radiating surfaces. If ducts and pipes are the source of noise and are isolated properly, possible remedies to reduce noise include changing flow conditions, installing silencers, and/or wrapping the duct or pipe with an acoustical barrier or lagging such as a lead blanket or other materials suitable for the location (see Chapter 49).

4. If noise is coming through the walls, ceiling, or floor, check for any openings to adjoining shafts or equipment rooms, and check vibration isolation systems to ensure that there is no structure-borne transmission from nearby equipment rooms or shafts.

5. Noise traced to air outlets or returns usually requires careful evaluation by an engineer or acoustical consultant to determine the source and proper corrective action (see Chapter 49). In general, air outlets can be selected to meet any acoustical design goal by keeping the velocity sufficiently low. For any given outlet, sound level increases with an increase in airflow velocity and doubling the velocity can increase this the sound level by 12 to 15 dB. Approach conditions caused by improperly located control dampers or improperly sized diffuser necks can increase these sound levels by 10 to 20 dB. Using variable-frequency drive (VFD) speed controllers on air-handling units can help evaluate air velocity concerns. Dampers used to limit airflow typically increase these sound levels.

   A simple, effective instrument that aids in locating noise sources is a microphone mounted on a pole. It can be used to localize noises in hard-to-reach places, such as hung ceilings and behind heavy furniture.

6. If noise is traced to an air outlet, measure the A-weighted sound level close to it but with no air blowing against the microphone. Then, remove the inner assembly or core of the air outlet and repeat the reading with the meter and the observer in exactly the same position as before. If the second reading is more than 3 dB below the first, a significant amount of noise is caused by airflow over the vanes of the diffuser or grille. In this case, check whether the system is balanced properly. As little as 10% too much air increases the sound generated by an air outlet by 2 dB. As a last resort, a larger air outlet could be substituted to obtain lower air velocities and hence less turbulence for the same air quality. Before this is considered, however, the air approach to the outlet should be checked.

   Noise far exceeding the normal rating of a diffuser or grille is generated when a throttled damper is installed close to it. Air jets impinge on the vanes or cones of the outlet and produce **edge tones** similar to the hiss heard when blowing against the edge of a ruler. The material of the vanes has no effect on this noise, although loose vanes may cause additional noise from vibration.

   When balancing air outlets with integral volume dampers, consider the static pressure drop across the damper, as well as the air quantity. Separate volume dampers should be installed sufficiently upstream from the outlet so that there is no jet impingement. Plenum inlets should be brought in from the side, so that jets do not impinge on the outlet vanes.

7. If air outlets are eliminated as sources of excessive noise, inspect the fan room. If possible, change fan speed by about 10%. If resonance is involved, this small change can make a significant difference.

8. Sometimes fans are poorly matched to the system. If a belt-driven fan delivers air at a higher static pressure than is needed to move the design air quantity through the system, reduce fan speed by changing sheaves. If the fan does not deliver enough air, consider increasing fan speed only after checking the duct system for leakage. Turbulence in the air approach to the fan inlet increases fan sound generation and decreases its air capacity. Other parts that may cause excessive turbulence are dampers, duct bends, and sudden enlargements or contractions of the duct. When investigating fan noise, seek assistance from the fan supplier or manufacturer.

9. If additional acoustical treatment is to be installed in the ductwork, obtain a frequency analysis. This involves the use of an octave-band analyzer and should generally be left to a trained engineer or acoustic consultant.

Testing for Vibration

Vibration testing is necessary to ensure that (1) equipment is operating within satisfactory vibration levels and (2) objectionable vibration and noise are not transmitted to the building structure. Although these two factors are interrelated, they are not necessarily interdependent. A different solution is required for each, and it is essential to test both the isolation and vibration levels of equipment. When measured routinely at the same location, vibration can be used for predictive maintenance.

General Procedure.

1. Verify final system balancing is complete.

2. Make a visual check of all equipment for obvious errors that must be corrected immediately.

3. Make sure all isolation is free-floating and not short-circuited by obstruction between equipment or equipment base and building structure.
4. Conduct bump test to determine the natural frequency.
5. Energize the system for an aural check of any obviously rough operation. Checking bearings with vibration measurement instrumentation is especially important because bearings can become defective in transit and/or if equipment was not properly stored, installed, or maintained. Defective bearings should be replaced immediately to avoid damage to the shaft and other components.
6. Set or drive equipment and systems so that final vibration tests are made on equipment as it will actually be operating.
7. Test equipment vibration.

Instruments. Although instruments are not required to test vibration isolation systems, they are essential to test equipment vibration properly.

Sound-level meters and **computer-driven sound-measuring systems** are the most useful instruments for measuring and evaluating vibration. Usually, they are fitted with accelerometers or vibration pickups for a full range of vibration measurement and analysis. Other instruments used for testing vibration in the field are described as follows.

Reed vibrometers are relatively inexpensive and are often used for testing vibration, but their relative inaccuracy limits their usefulness.

Vibrometers are moderately priced and measure vibration amplitude by means of a light beam projected on a graduated scale.

Vibrographs are moderately priced mechanical instruments that measure both amplitude and frequency. They provide a chart recording amplitude, frequency, and actual wave form of vibration. They can be used for simple, accurate determination of the natural frequency of shafts, components, and systems by a **bump test**.

Reed vibrometers, vibrometers, and vibrographs have largely been supplanted by electronic meters that are more accurate and have become much more affordable.

Vibration meters are moderately priced, relatively simple-to-use modern electronic instruments that measure the vibration amplitude. They provide a single broadband (summation of all frequencies) number identifying the magnitude of the vibration level. Both analog and digital readouts are common.

Vibration analyzers are relatively expensive electronic instruments that measure amplitude and frequency, usually incorporating a variable filter.

Strobe lights are often used with many of the other instruments for analyzing and balancing rotating equipment.

Stethoscopes are available as inexpensive mechanic's type (basically, a standard stethoscope with a probe attachment), relatively inexpensive models incorporating a tunable filter, and moderately priced powered types that electronically amplify sound and provide some type of meter and/or chart recording.

The choice of instruments depends on the test. Vibrometers and vibration meters can be used to measure vibration amplitude as an acceptance check. Because they cannot measure frequency, they cannot be used for analysis and primarily function as a go/no-go instrument. The best acceptance criteria consider both amplitude and frequency. Anyone seriously concerned with vibration testing should use an instrument that can determine frequency as well as amplitude, such as a vibrograph or vibration analyzer.

Vibration measurement instruments (both meters and analyzers) made specifically for measuring machinery vibration typically use **moving coil velocity transducers**, which are sizable and rugged. These are typically limited to a lower frequency of 500 cycles per minute (cpm) [8.33 Hz] with normal calibration. If measuring very-low-speed machinery such as large fans, cooling towers, or compressors operating below this limit, use an adjustment factor provided by the instrument manufacturer or use an instrument with a lower low-frequency limit, which typically uses a smaller accelerometer as the vibration pickup transducer.

Testing Vibration Isolation.

1. Ensure that equipment is **free-floating** by applying an unbalanced load, which should cause the equipment to move freely and easily. On floor-mounted equipment, check that there are no obstructions between the base or foundation and the building structure that would cause transmission while still permitting equipment to rock relatively free because of the application of an unbalanced force (Figure 19). On suspended equipment, check that hanger rods are not touching the hanger. Rigid connections such as pipes and ducts can prohibit mounts from functioning properly and from providing a transmission path. Note that the fact that the equipment is free floating does not mean that the isolators are functioning properly. For example, a 500 revolutions per minute (rpm) fan on isolators with a natural frequency of 500 cpm (8.33 Hz) could be free-floating but would actually be in resonance, resulting in transmission to the building and excessive movement.
2. Determine whether isolators are adjusted properly and providing desired isolation efficiency. All isolators supporting a piece of equipment should have approximately the same deflection (i.e., they should be compressed the same under the equipment). If not, they have been improperly adjusted, installed, or selected; this should be corrected

immediately. Note that isolation efficiency cannot be checked by comparing vibration amplitude on equipment to amplitude on the structure (Figure 20).

The only accurate check of isolation efficiencies is to compare vibration measurements of equipment operating with isolators to measurements of equipment operating without isolators. Because this is usually impractical, it is better to check whether the isolator's deflection is as specified and whether the specified or desired isolation efficiency is being provided. Figure 21 shows natural frequency of isolators as a function of deflection and indicates the theoretical isolation efficiencies for various frequencies at which the equipment operates.

Although it is easy to determine the deflection of spring mounts by measuring the difference between the free heights with a ruler (information as shown on submittal drawings or available from a manufacturer), these measurements are difficult with most pad or rubber mounts. Further, most pad and rubber mounts do not lend themselves to accurate determination of natural frequency as a function of deflection. For these mounts, the most practical approach is to check that there is no excessive vibration of the base and no noticeable or objectionable vibration transmission to the building structure.

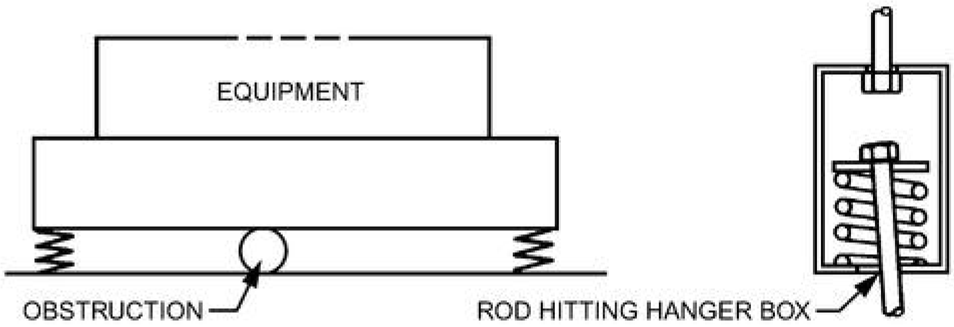

Figure 19. Obstructed Isolation Systems

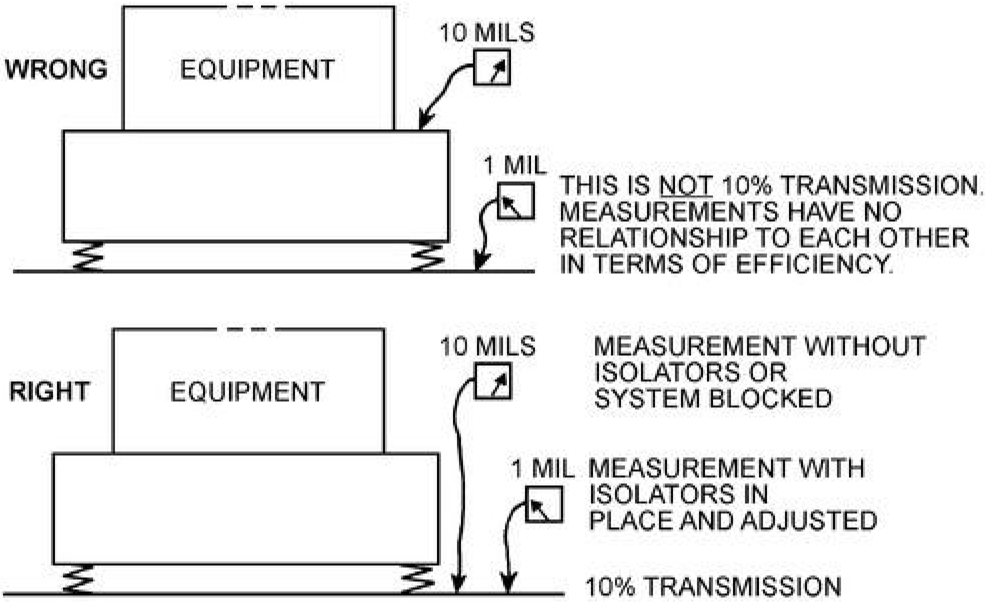

Figure 20. Testing Isolation Efficiency

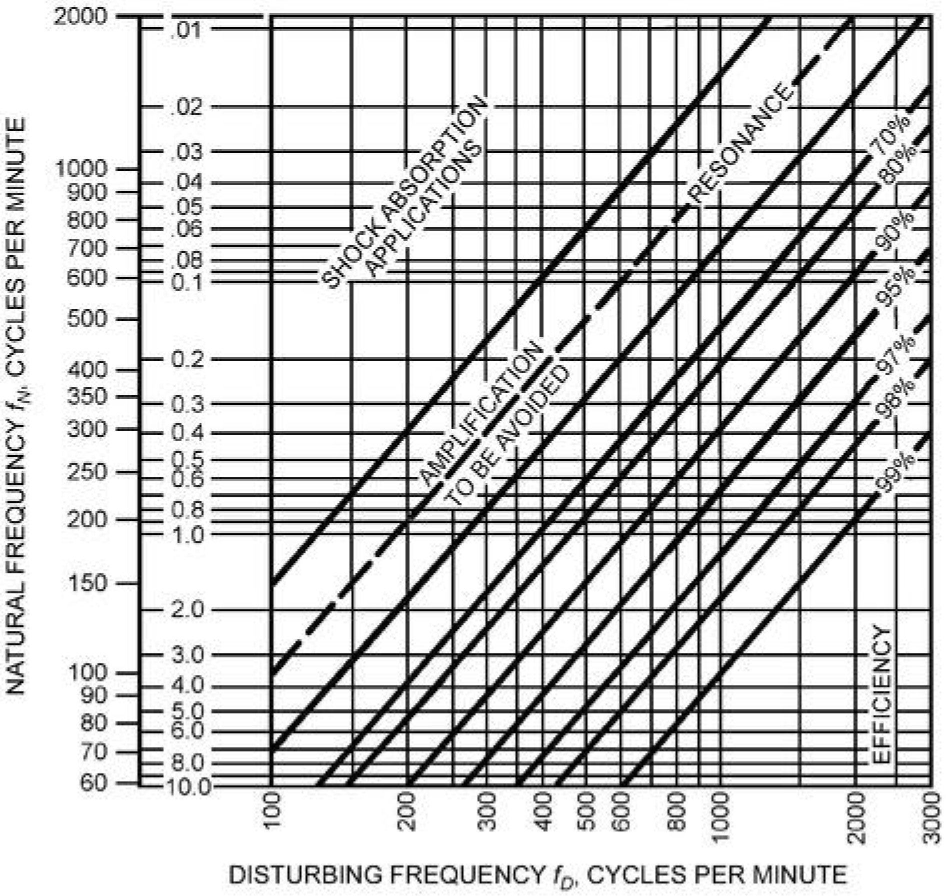

Figure 21. Isolator Natural Frequencies and Efficiencies

If isolators are in the 90% efficiency range and there is transmission to the building structure, either the equipment is operating roughly or there is a flanking path of transmission, such as connecting piping or obstruction, under the base.

Testing Equipment Vibration. Testing equipment vibration is necessary as an acceptance check to determine whether equipment is functioning properly and to ensure that objectionable vibration and noise are not transmitted. Although a person familiar with equipment can determine when it is operating roughly, instruments are usually required to determine accurately whether vibration levels are satisfactory.

Vibration Tolerances. Vibration tolerance criteria are listed in Table 45 of Chapter 49. These criteria are based on equipment installed on vibration isolators and can be met by any reasonably smoothly running equipment. Note that values in Chapter 49 are based on root-mean-square (RMS) values; other sources often use peak-to-peak or peak values, especially for displacements. For sinusoid responses, it is simple to obtain peak from RMS values, but in application the relationship may not be so straightforward. The main advantage of RMS is that the same instrumentation can be used for both sound and vibration measurements by simply changing the transducer. Also, there is only one recognized reference level for the decibel used for sound-pressure levels, but for vibration levels there are several recognized ones but no single standard. A common mistake in interpreting vibration data is misunderstanding the reference level and whether the vibration data are RMS, peak-to-peak, or peak values. Use great care in publishing and interpreting vibration data and converting to and from linear absolute values and levels in decibels.

Procedure for Testing Equipment Vibration.

1. Determine operating speeds of equipment from nameplates, drawings, or a speed-measuring device such as a tachometer or strobe, and indicate them on the test form. For any equipment where the driving speed (motor) is different from the driven speed (e.g., fan wheel, rotor, impeller) because of belt drive or gear reducers, indicate both driving and driven speeds.

2. Determine acceptance criteria from specifications, and indicate them on the test form. If specifications do not provide criteria, use those shown in Chapter 49.

3. Ensure that the vibration isolation system is functioning properly (see the section on Testing Vibration Isolation).

4. Conduct bump test to determine the natural frequency. This can be accomplished by placing the accelerometer and taping or bumping the bearing or motor with a rubber hammer.

5. Energize equipment and make visual and aural checks for any apparent rough operation. Any defective bearings, misalignment, or obvious rough operation should be corrected before proceeding further. If not corrected,

equipment should be considered unacceptable.

6. Measure and record vibration at bearings of driving and driven components in horizontal, vertical, and, if possible, axial directions. At least one axial measurement should be made for each rotating component (fan motor, pump motor).

7. Evaluate measurements.

Evaluating Vibration Measurements.

Amplitude Measurement. When specification for acceptable equipment vibration is based on amplitude measurements only, measurements can be made with an instrument that measures only amplitude (e.g., a vibration meter or vibrometer),

- No measurement should exceed specified values or values shown in Tables 45 or 46 of Chapter 49, taking into consideration reduced values for equipment installed on inertia blocks

- No measurement should exceed values shown in Tables 45 or 46 of Chapter 49 for driving and driven speeds, taking into consideration reduced values for equipment installed on inertia blocks. For example, with a belt-driven fan operating at 800 rpm and having an 1800 rpm driving motor, amplitude measurements at fan bearings must be in accordance with values shown for 800 cpm (13.3 Hz), and measurements at motor bearings must be in accordance with values shown for 1800 cpm (30 Hz). If measurements at motor bearings exceed specified values, take measurements of the motor only with belts removed to determine whether there is feedback vibration from the fan.

- No axial vibration measurement should exceed maximum radial (vertical or horizontal) vibration at the same location.

Amplitude and Frequency Measurement. When specification for acceptable equipment vibration is based on both amplitude and frequency measurements must be made with instruments that measure both amplitude and frequency (e.g., a vibrograph or vibration analyzer),

- Amplitude measurements at driving and driven speeds should not exceed specified values or values shown in Tables 45 or 46 of Chapter 49, taking into consideration reduced values for equipment installed on inertia blocks. Measurements that exceed acceptable amounts may be evaluated as explained in the section on Vibration Analysis.

- Axial vibration measurements should not exceed maximum radial (vertical or horizontal) vibration at the same location.

- The presence of any vibration at frequencies other than driving or driven speeds is generally reason to rate operation unacceptable; this vibration should be analyzed as explained in the section on Vibration Analysis.

Vibration Analysis. The following guide covers most vibration problems that may be encountered.

Axial Vibration Exceeds Radial Vibration. When the amplitude of axial vibration (parallel with shaft) at any bearing exceeds radial vibration (perpendicular to shaft, vertical or horizontal), it usually indicates misalignment, most common on direct-driven equipment because flexible couplings accommodate parallel and angular misalignment of shafts. This misalignment can generate forces that cause axial vibration, which can cause premature bearing failure, so misalignment should be checked carefully and corrected promptly. Other possible causes of large-amplitude axial vibration are resonance, defective bearings, insufficient rigidity of bearing supports or equipment, and loose hold-down bolts.

Vibration Amplitude Exceeds Allowable Tolerance at Rotational Speed. The allowable vibration limits established by Table 41 of Chapter 49 are based on vibration caused by rotor imbalance, which results in vibration at rotational frequency. Although vibration caused by imbalance must be at the frequency at which the part is rotating, a vibration at rotational frequency does not have to be caused by imbalance. An unbalanced rotating part develops centrifugal force, which causes it to vibrate at rotational frequency. Vibration at rotational frequency can also result from other conditions such as a bent shaft, an eccentric sheave, misalignment, and resonance. If vibration amplitude exceeds allowable tolerance at rotational frequency, the following steps should be taken before performing field balancing of rotating parts:

1. Check vibration amplitude as equipment goes up to operating speed and as it coasts to a stop. Any significant peaks at or near operating speed, as shown in Figure 22, indicate probable resonance (i.e., some part having a natural frequency close to the operating speed, resulting in greatly amplified levels of vibration).

   A bent shaft or eccentricity usually causes imbalance that results in significantly higher vibration amplitude at lower speeds, as shown in Figure 23 whereas vibration caused by imbalance generally increases as speed increases.

If a bent shaft or eccentricity is suspected, check the dial indicator. A bent shaft or eccentricity between bearings as shown in Figure 24A can usually be compensated for by field balancing, although some axial vibration might remain. Field balancing cannot correct vibration caused by a bent shaft on direct-connected equipment, on belt-driven equipment where the shaft is bent at the location of sheave, or if the sheave is eccentric (Figure 24B). This is because the center-to-center distance of the sheaves fluctuates, each revolution resulting in vibration.

2. For belt- or gear-driven equipment where vibration is at motor driving frequency rather than driven speed, it is best to disconnect the drive to perform tests. If the vibration amplitude of the motor operating by itself does not exceed specified or allowable values, excessive vibration (when the drive is connected) is probably a function of bent shaft, misalignment, eccentricity, resonance, or loose hold down bolts.
3. Vibration caused by imbalance can be corrected in the field by firms specializing in this service or by testing personnel if they have appropriate equipment and experience.

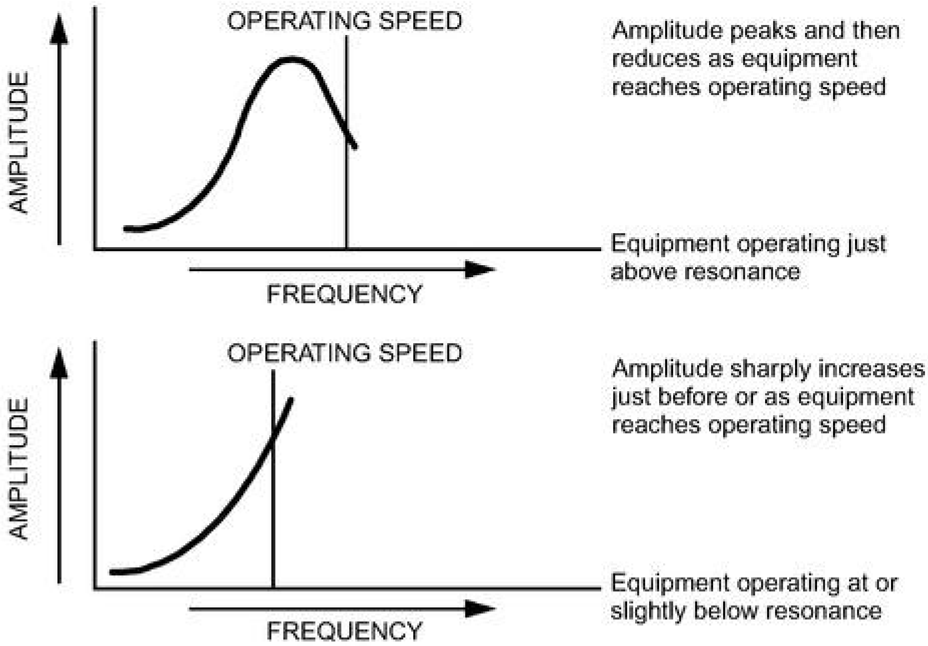

Figure 22. Vibration from Resonant Condition

Vibration at Other than Rotational Frequency. Vibration at frequencies other than driving and driven speeds is generally considered unacceptable. Table 4 shows some common conditions that can cause vibration at other than rotational frequency.

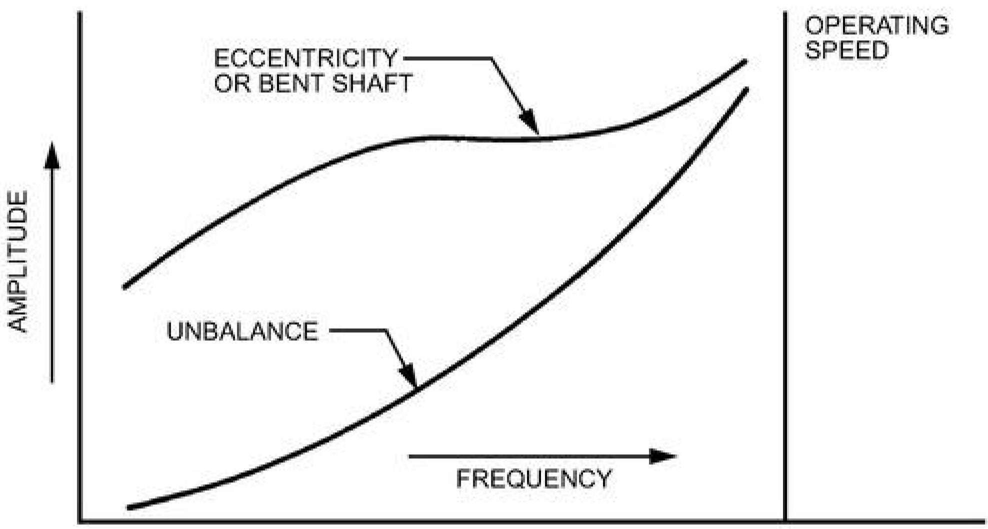

Figure 23. Vibration Caused by Eccentricity

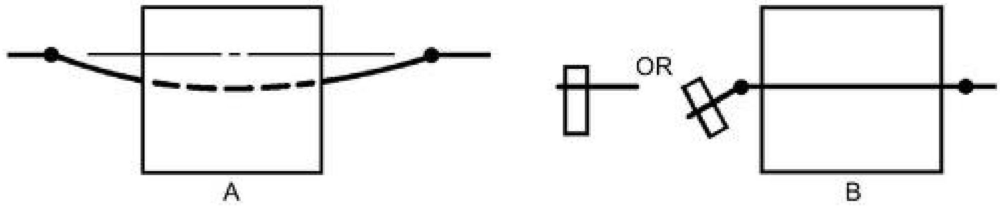

Figure 24. Bent Shafts

Table 4 Common Causes of Vibration Other than Unbalance at Rotation Frequency

Frequency	Source
0.5 × rpm	Vibration at approximately 0.5 rpm can result from improperly loaded sleeve bearings. This vibration will usually disappear suddenly as equipment coasts down from operating speed.
2 × rpm	Equipment is not tightly secured or bolted down.
2 × rpm	Misalignment of couplings or shafts usually results in vibration at twice rotational frequency and generally a relatively high axial vibration.
Many × rpm	Defective antifriction (ball, roller) bearings usually result in low-amplitude, high-frequency, erratic vibration. Because defective bearings usually produce noise rather than any significantly measurable vibration, it is best to check all bearings with a listening device.

Resonance. If resonance is suspected, determine which part of the system is in resonance.

Isolation Mounts. The natural frequency of the most commonly used spring mounts is a function of spring deflection, as shown in Figure 25, and it is relatively easy to calculate by determining the difference between the free and operating height of the mount, as explained in the section on Testing Vibration Isolation. This technique cannot be applied to rubber, pad, or fiberglass mounts, which have a natural frequency in the 300 to 3000 cpm (5 to 50 Hz) range. Natural frequency for such mounts is determined by a bump test. Any resonance with isolators should be immediately corrected because it results in excessive movement of equipment and more transmission to the building structure than if equipment were attached solidly to the building (installed without isolators).

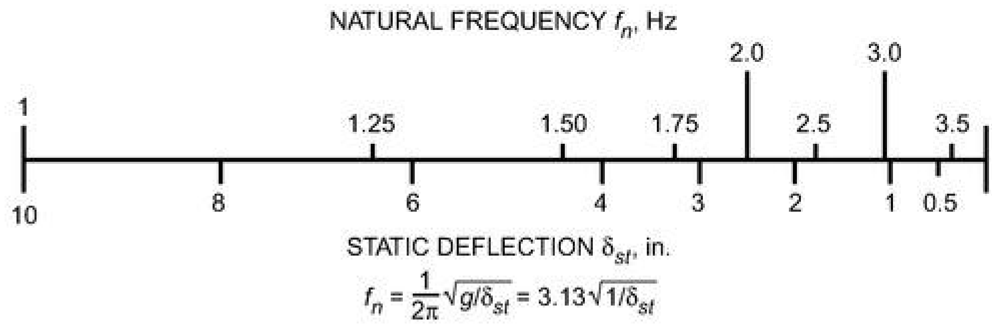

Figure 25. Natural Frequency of Vibration Isolators

Components. Resonance can occur with any shaft, structural base, casing, and connected piping. The easiest way to determine natural frequency is to perform a bump test with a vibration spectrum analyzer.

Checking for Vibration Transmission. The source of vibration transmission can be checked by determining frequency with a vibration analyzer and tracing back to equipment operating at this speed. However, the easiest and usually best method (even if test equipment is being used) is to shut off components one at a time until the source of transmission is located. Most transmission problems cause disturbing noise; listening is the most practical approach to determine a noise source because the ear is usually better than instruments at distinguishing small differences and changes in character and amount of noise. Where disturbing transmission consists solely of vibration, an instrument will probably be helpful, unless vibration is significantly above the sensory level of perception. Vibration below sensory perception is generally not objectionable.

If equipment is located near the affected area, check isolation mounts and equipment vibration. If vibration is not being transmitted through the base, or if the area is remote from equipment, the probable cause is transmission through connected piping and/or ducts. Ducts can usually be isolated by isolation hangers. However, transmission through connected piping is very common and presents many problems that should be understood before attempting to correct them (see the following section).

Vibration and Noise Transmission in Piping. Vibration and noise in connected piping can be generated by either equipment (e.g., pump or compressor) or flow (velocity). Mechanical vibration from equipment can be transmitted through the walls of pipes or by a water column. Flexible pipe connectors, which provide system flexibility to permit isolators to function properly and protect equipment from stress caused by misalignment and thermal expansion, can be useful in attenuating mechanical vibration transmitted through a pipe wall. However, they rarely suppress flow vibration and noise and only slightly attenuate mechanical vibration as transmitted through a water column.

Tie rods are often used with flexible rubber hose and rubber expansion joints (Figure 26). Although they accommodate thermal movements, they hinder vibration and noise isolation. This is because pressure in the system causes the hose or joint to expand until resilient washers under tie rods are virtually rigid. To isolate noise adequately with a flexible rubber connector, tie rods and anchor piping should not be used. However, this technique generally cannot be used with pumps on spring mounts, which would still permit the hose to elongate. Flexible metal hose can be used with spring-isolated pumps because wire braid serves as tie rods; metal hose controls vibration but not noise.

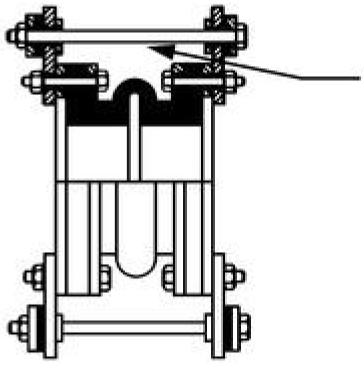

Figure 26. Typical Tie Rod Assembly

Problems of transmission through connected piping are best resolved by changes in the system to reduce noise (improve flow characteristics, reduce impeller size) or by completely isolating piping from the building structure. Note, however, that it is almost impossible to isolate piping completely from the structure, because the required resiliency is inconsistent with rigidity requirements of pipe anchors and guides. Chapter 49 contains information on flexible pipe connectors and resilient pipe supports, anchors, and guides, which should help resolve any piping noise transmission problems.

16. FIELD SURVEY FOR ENERGY AUDIT

An energy audit is an organized survey of a specific building to identify and measure all energy uses, determine probable sources of energy losses, and list energy conservation opportunities. This is usually performed as a team effort under the direction of a qualified energy engineer. The field data can be gathered by firms employing technicians trained in testing, adjusting, and balancing. Procedures for energy audits can be found in ASHRAE (2011).

Instruments

To determine a building's energy use characteristics, existing conditions must be accurately measured with proper instruments. Accurate measurements point out opportunities to reduce waste and provide a record of the actual conditions in the building before energy conservation measures were taken. They provide a compilation of installed equipment data and a record of equipment performance before changes. Judgments will be made based on the information gathered during the field survey; that which is not accurately measured cannot be properly evaluated.

Generally, instruments used for testing, adjusting, and balancing are sufficient for energy conservation surveying. Possible additional instruments include a power factor meter, light meter, combustion testing equipment, refrigeration gages, and equipment for recording temperatures, fluid flow rates, and energy use over time. Only high-quality instruments should be used.

Observation of system operation and any information the technician can obtain from the operating personnel pertaining to the operation should be included in the report.

Data Recording

Organized record keeping is extremely important. A camera is also helpful. Photographs of building components and mechanical and electrical equipment can be reviewed later when the data are analyzed.

Data sheets for energy conservation field surveys contain different and, in some cases, more comprehensive information than those used for testing, adjusting, and balancing. Generally, the energy engineer determines the degree of fieldwork to be performed; data sheets should be compatible with the instructions received.

Building Systems

The most effective way to reduce building energy waste is to identify, define, and tabulate the energy load by building system. For this purpose, load is defined as the quantity of energy used in a building, or by one of its subsystems, for a given period. By following this procedure, the most effective energy conservation opportunities can be achieved more quickly because high priorities can be assigned to systems that consume the most energy.

A building can be divided into nonenergized and energized systems. Nonenergized systems do not require external energy sources such as electricity and fuel. Energized systems (e.g., mechanical and electrical systems) require external energy. Energized and nonenergized systems can be divided into subsystems defined by function.

Nonenergized Systems. Nonenergized subsystems include building site, envelope, and interior; building use; and building operation.

Building Site, Envelope, and Interior. These subsystems should be surveyed to determine how they can be modified to reduce the building load that the mechanical and electrical systems must meet (without adversely affecting the building's appearance). It is important to compare actual conditions with conditions assumed by the designer, so that mechanical and electrical systems can be adjusted to balance their capacities to satisfy actual needs.

Building Use. These loads can be classified as people occupancy or operation loads. People occupancy loads are related to schedule, density, and mixing of occupancy types (e.g., process and office). People operation loads are varied and include operation of manual window shading devices; setting of room thermostats; and conservation-related habits such as turning off lights, closing doors and windows, turning off energized equipment when not in use, and not wasting domestic hot or chilled water.

Building Operation. This subsystem consists of the operation and maintenance of all the building subsystems. The load on the building operation subsystem is affected by factors such as the time at which janitorial services are performed, janitorial crew size and time required to clean, amount of lighting used to perform janitorial functions, quality of equipment maintenance program, system operational practices, and equipment efficiencies.

Energized Systems. Energized subsystems of a building generally include plumbing, heating, ventilating, cooling, space conditioning, control, electrical, and food service. Although these systems are interrelated and often use common components, logical organization of data requires evaluating the energy use of each subsystem as independently as possible. In this way, proper energy conservation measures for each subsystem can be developed.

Process Loads

In addition to building subsystem loads, the process load in most buildings must be evaluated by the energy field auditor. Most tasks not only require energy for performance, but also affect the energy consumption of other building subsystems. For example, if a process releases large amounts of heat to the space, the process consumes energy and also imposes a large load on the cooling system.

Guidelines for Developing Field Study Form

The following checklist outlines requirements for a field study form, needed to conduct an energy audit.

Inspection and Observation of All Systems. Record physical and mechanical condition of the following:

- Fan blades, fan scroll, drives, belt tightness, and alignment
- Filters, coils, and housing tightness
- Ductwork (equipment room and space, where possible)
- Strainers
- Insulation ducts and piping
- Makeup water treatment and cooling tower

Interview of Physical Plant Supervisor. Record answers to the following survey questions:

- Is the system operating as designed? If not, what changes have been made to ensure its performance?
- Have there been modifications or additions to the system?
- If the system has had a problem, list problems by frequency of occurrence.
- Are any systems cycled? If so, which systems, when, and would building load allow cycling systems?

Recording System Information. Record the following system/equipment identification:

- *Type of system.* Single-zone, multizone, dual-duct, low- or high-velocity, reheat, variable-volume, or other

- *System arrangement*. Fixed minimum outdoor air, no relief, gravity or power relief, economizer gravity relief, exhaust return, or other
- *Air-handling equipment.* (Supply, return, and exhaust) manufacturer, model, size, type, and class of fans; dampers (vortex, scroll, or discharge); motors manufacturer, power requirement, full-load amperes, voltage, phase, and service factor
- *Chilled- and hot-water coils.* Area, tubes on face, fin spacing, and number of rows (coil data necessary when shop drawings are not available)
- *Terminals.* High-pressure mixing box manufacturer, model, and type (reheat, constant-volume, variable-volume, induction); grilles, registers, and diffusers manufacturer, model, style, and correction factor to convert field-measured velocity to flow rate
- *Main heating and cooling pumps, over 5 hp.* Manufacturer, pump service and identification, model, size, impeller diameter, speed, flow rate, head at full flow, and head at no flow; motor data (power, speed, voltage, amperes, and service factor)
- *Refrigeration equipment.* Chiller manufacturer, type, model, serial number, nominal tons, brake horsepower, total heat rejection, motor (horsepower, amperes, volts), chiller pressure drop, entering and leaving chilled water temperatures, condenser pressure drop, condenser entering and leaving water temperatures, running amperes and volts, no-load running amperes and volts
- *Cooling tower.* Manufacturer, size, type, nominal tons, range, flow rate, and entering wet-bulb temperature
- *Heating equipment.* Boiler (small through medium) manufacturer, fuel, energy input (rated), and heat output (rated)

Recording Test Data. Record the following test data:

- *Systems in normal mode of operation (if possible).* Fan motor running amperes and volts and power factor (over 5 hp; fan speed, total air (pitot tube traverse where possible), and static pressure (discharge static minus inlet total); static profile drawing (static pressure across filters, heating coil, cooling coil, and dampers); static pressure at ends of runs of the system (identifying locations).
- *Cooling coils.* Entering and leaving dry- and wet-bulb temperatures, entering and leaving water temperatures, coil pressure drop (where pressure taps permit and manufacturer’s ratings can be obtained), flow rate of coil (when other than fan), outdoor wet and dry bulb, time of day, and conditions (sunny or cloudy).
- *Heating coils.* Entering and leaving dry-bulb temperatures, entering and leaving water temperatures, coil pressure drop (where pressure taps permit and manufacturer’s ratings can be obtained), and flow rate through coil (when other than fan).
- *Pumps.* No-flow head, full-flow discharge pressure, full-flow suction pressure, full-flow differential pressure, motor running amperes and volts, and power factor (over 5 hp).
- *Chiller (under cooling load conditions).* Chiller pressure drop, entering and leaving chilled water temperatures, condenser pressure drop, entering and leaving condenser water temperatures, running amperes and volts, no-load running amperes and volts, chilled water on and off, and condenser water on and off.
- *Cooling tower.* Waterflow rate in tower, entering and leaving water temperatures, entering and leaving wet bulb, fan motor (amperes, volts, power factor [over 5 hp], and ambient wet bulb).
- *Boiler (full fire).* Input energy (if possible), percent CO_2, stack temperature, efficiency, and complete Orsat test on large boilers.
- *Boiler controls.* Description of operation.
- *Temperature controls.* Operating and set-point temperatures for mixed air controller, leaving air controller, hot-deck controller, cold-deck controller, outdoor reset, interlock controls, and damper controls; description of complete control system and any malfunctions.
- Outdoor air intake versus exhaust air. Total airflow measured by pitot tube traverses of both outdoor air intake and exhaust air systems, where possible. Determine whether an imbalance in the exhaust system causes infiltration. Observe exterior walls to determine whether outdoor air can infiltrate return air (record outdoor air, return air, and return air plenum dry- and wet-bulb temperatures). The greater the differential between outdoor and return air, the more evident the problem will be.

17. TAB REPORTS

This section sets forth an outline for the procedures and forms which make up the final report of operating conditions.

Supervising personnel should use a logical approach in preparing forms and recording data. This section will list form titles and entries commonly used, allowing for design suited to each particular job. All entries will not be required in every situation. Many excellent forms have been developed by various associations but are available for use by their members only.

Accuracy in preparing the final report forms is important for several reasons:

- They provide a permanent record of system operating conditions after the last adjustments have been made.
- They confirm that prescribed procedures have been followed.
- They will serve as a reference that can be used by the owner for maintenance.
- They provide the designer with a system operational check and could serve as an aid in diagnosing problems.

All forms shall include identification of project, system/unit, location, date, technician, page number, and remarks.

General Items

The report should contain the following, as applicable:

Title page:

- Name and address of TAB firm
- Project name
- Location
- Architect
- Engineer
- Contractor
- Report date
- Signature of TAB firm person who approved report

Summary of comments:

- Design versus final performance
- Notable characteristics of system
- Description of systems operation sequence
- Summary of outdoor and exhaust flows to indicate amount of building pressurization

Nomenclature sheet:

- Codes for boxes, reheat coils, terminals, etc. (with data on manufacturer, type, size, fittings, etc.)
- Notes that explain in detail why certain final data in the body of the report deviate from design values

Test conditions (to be stated on the fan or pump performance form):

- Setting of outdoor, return, and exhaust dampers
- Condition of filters
- Cooling coil wet or dry
- Face and bypass damper setting at coil

- Fan drive setting (indicate setting
- percentage of maximum pitch diameter)
- Set points of variable flow controller
- Setting of supply air static pressure controller
- Other systems operating which affect performances

System Diagram

A single line diagram for schematic layout of air distribution systems and hydronic systems is highly recommended to ensure systematic and efficient procedures. Quantities of outdoor air, return air, relief air; sizes and airflow rates for main ducts; sizes and airflow rates for all air terminal devices, dampers, and other regulating devices should be shown. All air terminals should be numbered before filling out the air terminal device report. Though diagrams are suggested, the use of this form is not mandatory.

Air Apparatus Test Report

The performance of air handling apparatus with coils is to be reported. Motor voltage and amperage for three-phase motors should be reported for all three legs (T1, T2, and T3). If the design engineer did not specify a design quantity for any item in the test data section, place an X in the space for the design quantity and record the actual quantity. If available, include equipment manufacturer ratings in the design columns when design quantity is unknown. If motor ratings differ from design, provide an explanation at the bottom of the page. If there are split coils, record data for each airstream.

Unit Data

- Make/type
- Model number/size
- Serial number
- Arrangement/class
- Discharge
- Sheave make
- Sheave size/bore
- Number of belts/make/size
- Number of filters/type/size
- Make/frame
- hp/rpm
- Volts/phase/hertz
- Full load amps/service factor
- Sheave make
- Cooling coil differential static pressure
- Heating coil differential static pressure
- Outdoor airflow rate
- Return airflow rate
- Outdoor air damper position
- Return air damper position
- Vortex damper position

Motor Data

- Sheave size/bore
- Sheave adjustment

Test Data (list design and actual for each)

- Total airflow rate
- Total system static pressure
- Fan rpm
- Motor volts, T1-T2, T2-T3, T3-T1
- Motor amps, A1, A2, A3
- Discharge static pressure
- Filter differential static pressure
- Preheat coil differential static pressure

Apparatus Coil Test Report:

The performance of chilled water, hot water, steam, or DX coils, and for runaround heat recovery systems is to be reported.

Coil Data:

- System number
- Location
- Coil type
- Number of rows/fins
- Make/model
- Face area
- Tube size
- Tube/fin material
- Circuiting

Test Data: (list design and actual for each)

- Airflow rate
- Air velocity
- Air pressure drop
- Entering/leaving air (db/wb)
- Waterflow rate
- Water pressure differential
- Entering/leaving water temperature
- Exp. valve/refrigeration
- Refrigeration suction pressure
- Refrigeration suction temperature
- Inlet steam pressure

Gas/Oil Fired Heat Apparatus Test Report

Data for gas- or oil-fired devices, (e.g., unit heaters, duct furnaces, etc.) will be recorded. This report is not intended to be used in lieu of a factory startup equipment report, but could be used as a supplement. All available design data should be reported. Some information could apply to the burner motor, burner fan motor, unit air fan motor, etc., depending on the application or equipment. Therefore, designate the motor of the recorded data.

Unit Data:

- System number
- Location
- Make/type
- Model number/size
- Serial number
- Type fuel/input
- Output/Btu/h
- Ignition type
- Burner control
- Volts/phase/hertz
- hp/rpm
- Full load amps/service factor
- Sheave data

Test Data: (list design and actual for each)

- Airflow rate
- Entering/leaving air temperature
- Entering/leaving air pressure
- Low fire input
- High fire input
- Manifold pressure/CFH
- High limit setting
- Operating set point
- Voltage, T1-T2, T2-T3, T3-T1
- Amps, A1, A2, A3
- Heating value of fuel

Electric Coil/Duct Heater Test Report

Data for electric furnaces or for electric coils installed in built-up units or ducts will be recorded. "Minimum air velocity" is as recommended by manufacturers.

Unit Data:

- System/location
- Coil number
- kW
- Stages
- Volts/phase/Hertz
- Amps
- Airflow rate
- Face area
- Minimum air velocity

Test Data: (list design and actual for each)

- kW
- Air velocity
- Airflow rate
- Entering air temperature
- Leaving air temperature
- Voltage, T1-T2, T2-T3, T3-T1
- Amps, A1, A2, A3

Fan Test Report

The performance of all supply, return, and exhaust fans should be recorded.

Fan Data:

- System number
- Location
- Make/type
- Model number/size
- Serial number
- Arrangement/class
- Sheave make
- Sheave size/bore

Motor Data:

- Make/frame
- hp/rpm
- Volts/phase/Hertz
- Full load amps
- Service factor
- Sheave make
- Sheave size/bore
- Number of belts/make/size
- Sheave centerline distance and adjustment

Test Data: (list design and actual for each)

- Airflow rate
- Total system static pressure
- Fan rpm
- Discharge static pressure
- Suction static pressure
- Voltage, T1 T2, T2 T3, T3 T1
- Amps, Al, A2, A3

Duct Traverse Report

The results of a pitot tube traverse in all rectangular, round, and oval ducts shall be recorded. For rectangular duct traverses, make a grid representing the duct cross section with a box for each test point and its distance from sides of duct. It is recommended that the velocity pressures be recorded in one half of each box provided and then converted to velocities in the other half of the box at a later time. The velocities should be averaged, but do not average the velocity pressures. For round duct traverses, make a circle representing the duct cross section. Make columns with a number for each test point, along with its distance from sides of duct, and for velocity pressures or velocities taken at points across three diameters at a 60° angles to each other. For oval duct traverses, make columns with a number for each test point, its dimension along the major and minor axis, and velocity pressures or velocities taken at points across the two axes of the duct, or show on a traverse sheet the horizontal reading.

Data Reported:

- System/unit number
- Location/zone
- Traverse air temperature
- Duct static pressure
- Duct size
- Duct area
- Design velocity
- Design flow rate
- Actual average velocity
- Actual flow rate
- Barometric pressure

Air Terminal Device Report

The flow rate of all air terminal devices should be recorded. If the final adjusted flow rate of any air terminal device deviates from design by more than ±10%, a note indicating the amount of variance shall be recorded in the "remarks" section of the report to provide known or potential reasons for such deviation. All correction factors should be shown in the remarks column for all velocity measurement instruments.

Data Reported:

- System/unit number
- Location/zone
- Test apparatus
- Area served
- Air terminal device number (from system diagram)
- Air terminal device type/model
- Air terminal device size
- Design flow rate
- Design velocity
- Preliminary velocity (as needed)
- Make preliminary flow rate (as needed)
- Final velocity
- Final volume
- C_v/effective area

System Coil Report

The performance of reheat coils or the water coil on terminal units should be recorded.

Equipment Data:

- System/unit number
- Location/zone
- Room number/riser number
- Coil make
- Model/size
- Design flow rate
- Design water supply temperature
- Flow meter type/size

Test Data:

- Flow meter reading (if available)
- Design pressure drop
- Entering water pressure
- Leaving water pressure
- Actual pressure drop
- Design water temperature drop
- Entering/leaving water temperature
- Actual water temperature drop
- Design air pressure drop
- Entering/leaving air static pressure
- Actual air static pressure drop
- Design air temperature drop (cooling coil [db, wb] heating coil [db])
- Entering/leaving air temperature
- Actual air temperature drop

Packaged Chiller Test Report

The control settings and the entering and leaving conditions at the chiller should be recorded. This data should be substantially completed and verified by the manufacturers' representatives and/or the equipment owner or installing contractor before the HVAC distribution systems are balanced. Temperature and pressure differential readings of the chiller unit evaporator and condenser should be recorded during the TAB procedures. Describe the flow measuring device when used.

(List design and actual quantities where appropriate.)

Unit Data:

- Make/type
- Model number/size
- Serial number
- Capacity refrigerant
- Refrigerant
- Starter
- Heater size

Condenser Data:

- Condenser pressure/temperature
- Entering/leaving water pressure
- Water pressure drop
- Entering/leaving water temperature
- Entering/leaving air temperature
- Actual air temperature drop
- Water temperature drop

Evaporator Data:

- Evaporator pressure/temperature
- Entering/leaving water pressure
- Water pressure drop
- Entering/leaving water temperature
- Water temperature drop
- Waterflow rate

Compressor Data:

- Make/model
- Serial number
- Suction pressure/temperature
- Discharge pressure/temperature
- Oil pressure/temperature
- Voltage, T1-T2, T2-T3, T3-T1
- Amps, A1, A2, A3
- Kilowatt input
- Crankcase heater amps
- Chilled-water control setting
- Cond. water control setting
- Low-pressure cutout setting
- High-pressure cutout setting

Refrigeration Data:

- Oil level checked
- Oil failure sw. diff.
- Refrigeration level checked
- Relief valve setting
- Unloader set points
- Percent cylinders unloaded
- Purge operation checked
- Bearing temperature
- Vane position
- Demand limit

- Low-temperature cutout setting

Package Rooftop/Heat Pump A/C Unit Test Report

Test data from package units of all types shall be recorded. If the unit has components other than the evaporator fan, DX coil, and compressor and condenser fan(s), use the appropriate report forms for: water or steam coils, direct fired heaters, electric coils, or return air fans.

Unit Data:

- Make/model number
- Type/size
- Serial number
- Filter type/size
- Fan sheave make
- Fans sheave diameter/bore
- Number, make, and size of belts
- Type of heating section (use other appropriate form)

Motor Data:

- Make/frame
- hp/rpm
- Volts/phase/hertz
- Full-load amps/SF
- Sheave make
- Sheave diameter/bore
- Sheave centerline distance and adjustment

Evaporator Test Data: (list design and actual)

- Total airflow rate
- Total static pressure
- Discharge static pressure
- Suction static pressure
- Outdoor airflow rate
- Outdoor air db/wb
- Return airflow rate
- Return airflow db/wb
- Entering air db/wb
- Leaving air db/wb
- Fan rpm
- Voltage, T1-T2, T2-T3, T3-T1
- Amps, A1, A2, A3

Condenser Test Data: (list design and actual)

- Refrigerant weight
- Compressor manufacturer/number

- Compressor model/serial number
- Low ambient control
- Suction pressure/temperature
- Condenser pressure/temperature
- Crankcase motor amps
- Compressor volts, T1-T2, T2-T3, T3-T1
- Compressor amps, A1, A2, A3
- Low-/high-pressure cutout setting
- Number of fans/rpm
- Condenser fan power/airflow rate
- Condenser fan volts/amps/phase

Compressor and/or Condenser Test Report

Control settings, as well as entering and leaving conditions at the compressor and/or condenser, should be recorded. Because the balancing firm is not necessarily responsible for startup or the proper operation of the machine, this form does not attempt to indicate the performance or efficiency of the machine except as may be determined by the design engineer from the data contained therein.

These data should be substantially completed and verified by the manufacturers' representatives and/or the equipment owner or installing contractor before the HVAC distribution systems are balanced. Temperature and pressure differential readings of the unit should be recorded during the TAB procedures.

This report may also be used to record data for the refrigerant side of unitary systems, bare compressors, separate air-cooled condensers, or separate water-cooled condensers.

Unit Data:

- Unit make
- Unit model/serial number
- Compressor make
- Compressor model/serial number
- Refrigerant weight
- Low ambient control

Test Data: (list design and actual for each)

- Duct inlet/outlet static pressure
- Entering/leaving air db
- Cond. water temperature in/out
- Cond. water pressure in/out
- Control setting
- Unloader set points
- Low-/high-pressure cutout setting
- Suction pressure/temperature
- Cond. pressure temperature
- Oil pressure/temperature
- Voltage, T1 T2, T2 T3, T3 T1
- Amps, A1, A2, A3
- Kilowatt input
- Crankcase heater amps

- Number of fans/fan rpm/airflow rate
- Fan motor make/frame/power
- Fan motor volts/amps

Cooling Tower or Condenser Test Report

This data should be substantially completed and verified before the system is balanced. The pump data section is to be used for the recirculating pump in evaporative condensers, not the system used with cooling towers.

Unit Data:

- Make/type
- Model number/size
- Serial number
- Nominal capacity
- Refrigerant
- Water treatment

Pump Data:

- Make/model
- Pump serial number
- Motor make/frame
- Motor hp/rpm
- Volts/phase/hertz
- Waterflow rate

Fan Data:

- Number of fan motors
- Motor make/frame
- Motor hp/rpm
- Volts/phase/hertz
- Motor sheave diameter/bore
- Fan sheave diameter/bore
- Sheave centerline distance
- Number of belts/make/size

Air Data: (list design and actual for each)

- Duct airflow rate
- Duct inlet static pressure
- Duct outlet static pressure
- Average entering/leaving wb
- Ambient wb

Water Data: (list design and actual for each)

- Entering/leaving water pressure
- Water pressure drop
- Entering/leaving water temperature
- Water temperature drop

- Water flow rate
- Bleed waterflow rate

Heat Exchanger/Converter Test Report

The record final conditions for steam or hot water heat exchangers should be recorded.

Unit Data:

- Location
- Service
- Make/type
- Model number/size
- Serial number
- Rating

Steam Test Data: (list design and actual for each)

- Pressure
- Flow rate

Primary Test Data: (list design and actual for each)

- Entering/leaving temperature
- Temperature drop
- Entering/leaving pressure
- Pressure drop
- Waterflow rate

Secondary Test Data: (list design and actual for each)

- Entering/leaving temperatures
- Temperature differential
- Entering/leaving pressure
- Pressure differential
- Waterflow rate
- Control set point
- Circuiting type

Pump Test Report

The final data on each pump is to be recorded. The actual impeller diameter entry is that indicated by plotting the head curve based on a no-flow head test or by actual field measurement where possible.

Net positive suction head (NPSH) is important for pumps in open circuits and for pumps handling fluids at elevated temperatures.

Design Data:

- Service/location
- Make
- Model number
- Serial number
- Waterflow rate/head
- Required NPSH

- Pump rpm
- Impeller diameter
- Motor make/frame
- Motor hp/rpm
- Volts/phase/hertz
- Full-load amps/SF
- Seal type

Actual Test Data:

- Number of flow heads
- Actual impeller diameter
- Full open head
- Full open flow rate
- Final discharge pressure
- Final suction pressure
- Final head
- Final flow rate
- Voltage, T1-T2, T-T3, T3-T1
- Amps, A1, A2, A3

Boiler Test Report

The control settings and the entering and leaving conditions at the boiler should be recorded. Because the balancing firm is not necessarily responsible for start-up or the proper operation of the machine, these data do not attempt to indicate the performance or efficiency of the boiler except as may be determined by the design engineer from the data contained therein.

This report should be substantially completed and verified by the manufacturers' representatives and/or the installing contractor before the HVAC distribution systems are balanced. Temperature and/or pressure readings of the boiler should be entered during TAB procedures.

A flue gas analysis normally is not in the scope of TAB procedures, but data could be added in a commentary section if available and required by the engineer/owner.

Unit Data:

- Location/service
- Make/type
- Model number/size
- Serial number
- Fuel/input
- Number of passes
- Ignition type
- Burner control
- Volts/phase/hertz

Test Data: (list design and actual for each)

- Operating pressure/temperature
- Entering/leaving temperature

- Number of safety valves/size
- Safety valve settings
- High limit setting
- Operating control setting
- High fire set point
- Low fire set point
- Voltage, T1-T2, T2-T3, T3-T1
- Amps, A1, A2, A3
- Draft fan volts/amps
- Manifold pressure
- Safety controls check

Instrument Calibration Report

This report is to document the application and date of the most recent calibration test or calibration for each instrument used in the testing, adjusting, and balancing work.

Data Reported:

- Instrument/make
- Serial number
- Application
- Dates of use
- Date(s) of calibration

Component Failure Report

This report is intended to provide sufficient information to determine cause of failure and provide feedback to the manufacturer, designer, or installer. This report should be used as soon as a problem has occurred, and its inclusion in the final report is at the discretion of the balancer. It should be noted on the report, if appropriate, that the analysis and recommendations are not to be considered final or expert.

Data Reported:

- Project
- System
- Component
- Manufacturer
- Serial number
- Model number
- Date
- Architect/engineer
- Contractor
- Submittal data
- Description and problem
- Field test results
- Probable cause
- Recommendations

Reports should comply with ASHRAE *Standard* 111, be complete, and include the location of test drawings. An instrument list including serial numbers and current and future calibration dates should also be provided.

REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

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The preparation of this chapter is assigned to TC 7.7, Testing and Balancing.