ASHRAE Guideline 11-2018R

Public Review Draft

Field Testing of HVAC Control Components

First Public Review (July 2021)

(This document is out for revision publication public review. Only items in red are out for public review. Due to the reference updates, SRS will be acting as the revision PC. Any comments received that are technical in nature will go forward at the next revision process where a PC will be formed to respond to those comments.)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed guideline, go to the ASHRAE website at www.ashrae.org/standards-research--technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the guideline (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any guideline may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

The appearance of any technical data or editorial material in this public review document does not constitute endorsement, warranty, or guaranty by ASHARE of any product, service, process, procedure, or design, and ASHARE expressly disclaims such.

© 2021 ASHRAE. This draft is covered under ASHRAE copyright. Permission to reproduce or redistribute all or any part of this document must be obtained from the ASHRAE Manager of Standards, 1791 Tullie Circle, NE, Atlanta, GA 30329. Phone: 404-636-8400, Ext. 1125. Fax: 404-321-5478. E-mail: standards.section@ashrae.org.

ASHRAE, 1791 Tullie Circle, NE, Atlanta GA 30329-2305
ASHRAE Guideline Project Committee 11
Cognizant TC: 7.7, Testing and Balancing
SPLS Liaison: Erick A. Phelps

Thomas P. Schlahter*, Chair
Gerald J. Kettler*, Vice-Chair
Donald Prather*, Secretary

David E. Bornside*
Barry B. Bridges*
Darryl W. DeAngelis*

Frederick A. Lorch*
Robert J. Sibilski*

* Denotes members of voting status when the document was approved for publication

ASHRAE STANDARDS COMMITTEE 2018–2019

Donald M. Brundage, Chair
Walter T. Grondzik
Erick A. Phelps

Wayne H. Stoppelmoor, Jr., Vice-Chair
Vinod P. Gupta
David Robin

Els Baert
Susanna S. Hanson
Lawrence J. Schoen

Charles S. Barnaby
Roger L. Hedrick
Dennis A. Stanke

Niels Bidstrup
Rick M. Heiden
Richard T. Swierczyna

Robert B. Burkhead
Jonathan Humble
Russell C. Tharp

Michael D. Corbat
Kwang Woo Kim
Adrienne G. Thomle

Drury B. Crawley
Larry Kouma
Craig P. Wray

Julie M. Ferguson
R. Lee Millies, Jr.
Lawrence C. Markel, BOD ExO

Michael W. Gallagher
Karl L. Peterman
Michael CA Schwedler, CO

Steven C. Ferguson, Senior Manager of Standards

SPECIAL NOTE
This Guideline was developed under the auspices of ASHRAE. ASHRAE Guidelines are developed under a review process, identifying a Guideline for the design, testing, application, or evaluation of a specific product, concept, or practice. As a Guideline it is not definitive but encompasses areas where there may be a variety of approaches, none of which must be precisely correct. ASHRAE Guidelines are written to assist professionals in the area of concern and expertise of ASHRAE's Technical Committees and Task Groups.

ASHRAE Guidelines are prepared by Project Committees appointed specifically for the purpose of writing Guidelines. The Project Committee Chair and Vice-Chair must be members of ASHRAE; while other committee members may or may not be ASHRAE members, all must be technically qualified in the subject area of the Guideline.

Development of ASHRAE Guidelines follows procedures similar to those for ASHRAE Standards except that (a) committee balance is desired but not required, (b) an effort is made to achieve consensus but consensus is not required, (c) Guidelines are not appealable, and (d) Guidelines are not submitted to ANSI for approval.

The Senior Manager of Standards of ASHRAE should be contacted for
a. interpretation of the contents of this Guideline,
b. participation in the next review of the Guideline,
c. offering constructive criticism for improving the Guideline, or
d. permission to reprint portions of the Guideline.

DISCLAIMER
ASHRAE uses its best efforts to promulgate Standards and Guidelines for the benefit of the public in light of available information and accepted industry practices. However, ASHRAE does not guarantee, certify, or assure the safety or performance of any products, components, or systems tested, installed, or operated in accordance with ASHRAE’s Standards or Guidelines or that any tests conducted under its Standards or Guidelines will be nonhazardous or free from risk.

ASHRAE INDUSTRIAL ADVERTISING POLICY ON STANDARDS
ASHRAE Standards and Guidelines are established to assist industry and the public by offering a uniform method of testing for rating purposes, by suggesting safe practices in designing and installing equipment, by providing proper definitions of this equipment, and by providing other information that may serve to guide the industry. The creation of ASHRAE Standards and Guidelines is determined by the need for them, and conformance to them is completely voluntary.

In referring to this Standard or Guideline and in marking of equipment and in advertising, no claim shall be made, either stated or implied, that the product has been approved by ASHRAE.
ASHRAE STANDARDS COMMITTEE 2021-2022

Rick M. Heiden, Chair
Susanna S. Hanson, Vice Chair
Charles S. Barnaby
Robert B. Burkhead
Thomas E. Cappellin
Douglas D. Fick
Michael W. Gallagher
Patricia Graef
Srinivas Katipamula
Gerald J. Kettler
Essam E. Khalil
Malcolm D. Knight
Jay A. Kohler
Cesar L. Lim
Paul A. Lindahl, Jr.

James D. Lutz
Julie Majurin
Lawrence C. Markel
Margret M. Mathison
Gwelen Paliaga
Justin M. Prosser
David Robin
Lawrence J. Schoen
Steven C. Sill
Christian R. Taber
Russell C. Tharp
William F. Walter
Craig P. Wray
Jaap Hogeling, BOD ExO
Tim J. McGinn, CO

Connor Barbaree, Senior Manager of Standards
## CONTENTS

ASHRAE Guideline 11-2018
Field Testing of HVAC Controls Components

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>2</td>
</tr>
<tr>
<td>1 Purpose</td>
<td>2</td>
</tr>
<tr>
<td>2 Scope</td>
<td>2</td>
</tr>
<tr>
<td>3 Definitions</td>
<td>2</td>
</tr>
<tr>
<td>4 General Format for Testing</td>
<td>2</td>
</tr>
<tr>
<td>5 Device Testing—Basic Requirements</td>
<td>3</td>
</tr>
<tr>
<td>6 System Component Testing</td>
<td>15</td>
</tr>
<tr>
<td>7 Sequence of Operation</td>
<td>21</td>
</tr>
<tr>
<td>8 Problem Solving/Critical Testing</td>
<td>21</td>
</tr>
<tr>
<td>9 Documentation</td>
<td>22</td>
</tr>
<tr>
<td>10 References</td>
<td>22</td>
</tr>
<tr>
<td>Informative Appendix A: Instructions for Testing and for Completing Test Forms</td>
<td>23</td>
</tr>
<tr>
<td>Informative Appendix B: Tuning PI Controllers</td>
<td>26</td>
</tr>
</tbody>
</table>

### NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE website at www.ashrae.org/technology.

© 2018 ASHRAE
1791 Tullie Circle NE · Atlanta, GA 30329 · www.ashrae.org · All rights reserved.
ASHRAE is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
(This foreword is not a part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

ASHRAE Guideline 11 presents field testing procedures for specific devices that control the operation of an HVAC system. Field testing of HVAC controls components involves verifying the actual installation, location, and access to the various types of control devices used in HVAC systems. Some control devices can be tested on multiple levels, from a simple ON/OFF check to the computerized verification of performance criteria. The interaction and sequencing of controls devices is also covered. The results of the testing procedures define the operability of the device and ultimately the system.

The 2018 edition of Guideline 11 has been revised in several ways. The first change was to address newer direct digital control (DDC) technology but still allow the reader to understand the nuances of the older pneumatic systems that are still in use today. Secondly, redundant language was removed to make the guideline easier to read.


1. PURPOSE
This guideline provides procedures for field testing and adjusting of control components used in building heating, ventilating, and air-conditioning (HVAC) systems.

2. SCOPE
This guideline covers the procedures, formats, and methods necessary for evaluation and documentation of the performance of devices and systems that control HVAC systems.

3. DEFINITIONS
Definitions of terms used in this guideline can be found in ASHRAE Terminology of Heating, Ventilation, Air Conditioning, & Refrigeration and the ASHRAE Terminology online database.

control sensor: device or instrument designed to detect and measure a control variable.

control sensor accuracy: conformity of an indicated control sensor value to an accepted standard value or true value. Quantitatively, it should be expressed as an error or an uncertainty.

control sequence: an organized narration specifying how the integrated functions of a device, system, or facility will perform. It should incorporate energy efficiency and environmental concerns with detailed, comprehensive control strategies—i.e., how each individual piece of equipment will be controlled and what information and adjustment will be available to the user. These may be provided in a combination of narratives, diagrams, and point lists for every unique type of equipment and for each system.

control system: an arrangement of elements interconnected and interacting in such a way as to maintain or influence specified conditions in a prescribed manner.

4. GENERAL FORMAT FOR TESTING
4.1 Reasons for Testing. The components of control systems are essential for heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems to properly and efficiently perform their functions. Sensors monitor and report on conditions and equipment performance. Controllers perform the process supervision. Device operators execute the functions to produce proper unit outputs.

Each of these devices is designed to perform its basic function under a set of conditions defined in the design documents. The performance level of the device, the correct installation, and the correct operation of the system are verified under operating conditions. The documentation from these tests provides a verification of the device and system design and a record of initial performance.

4.2 Testing Parameters and Accessibility for Testing. The following parameters are necessary to properly test a device or system:

a. Prior to start of testing, verify that all equipment and components are installed correctly per design documents and/or manufacturer requirements.

b. Performance characteristics of the device, and the system design requirements, are understood by the tester.

c. Testing procedures are developed to make the test results reliable and understandable.

d. To be reliable and credible, tests are performed using the developed procedures with proper test equipment.

e. The test equipment is to be placed in a comparable position to verify operation of the device/system being tested.

f. Tests are performed during stable (noncycling) operating conditions.

Informative Note: These require physical access to the test site sufficient to install the test apparatus and to access the fluid being monitored.

4.3 General Testing Procedures
4.3.1 Testing Level Strategy. There are several levels or phases of testing. In some cases, only simple verification of
(This foreword is not a part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

This is a revision of Guideline 11-2018. This guideline was prepared under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interests of obtaining uniform guidelines throughout the industry.

Changes made for the 2021 revision include:
• Updated References
the installation and testing of control operation are necessary. At other times, the static and dynamic performance characteristics of the device or system may need to be examined to ensure expected control performance. In some cases, for problem systems, advanced analysis may be needed to solve a control problem. The function of the control device and the design requirements will determine the testing required.

4.3.1.1 Level 1: Installation Verification. Design, submittals, and installation of devices and subsystems are examined to ensure proper sizing, selection, and installation of a device or system. The location, position, and interconnection of devices are checked for installation and project requirements.

Performance testing begins with verifying the location, position, and interconnection of devices against the project requirements. Operational testing includes verifying the function of the control device. The design requirements will determine the testing required.

4.3.1.2 Level 2: Operational Testing. Sensor output signals (temperature, pressure, flow, humidity, etc.) are measured with a calibrated instrument to determine the accuracy of the installed device or system and to verify simple response under normal operating conditions. Sensors are checked at or near normal operating conditions.

Sequence and proper operation of system components and operators are checked for response to signals, correct direction of travel, and full required travel range in expected modes of operation.

4.3.1.3 Level 3: Performance Testing. These tests and observations are intended to verify that the devices and systems meet the design and operational requirements of the building.

The stability and repeatability of the device or system can be measured against a calibrated standard. Sensitivity and accuracy may be checked over the entire sensing range of the device. The required accuracy, the number and location of test points, and the number of cycles may be specified by the designer. This may require performance tests or simulations that provide system and device performance curves, time constants, hysteresis curves, and other related response criteria to provide diagnostic information. Some systems that are not performing as intended may require advanced analysis. This may include sophisticated test devices, performance simulations, and even removal and laboratory testing.

4.3.2 System Preparation. To test properly, verify that both the system and the devices are installed and in operation under conditions compatible with device capabilities and design specifications. Verify that access to both the device and its test ports are available. Controls are complete and functional. Design and submittal data are available. In many cases, the control devices will not control properly unless they are properly balanced. Therefore, the test and balance function is completed and integrated into the device testing procedures.

4.3.3 Equipment Selection and Preparation. Each device and type of test requires a specific type of test instrument and standard procedure. The test to be performed determines the selection of the test equipment as well as the supporting apparatus and documentation. Each task is to have testing criteria and requirements provided by the design professional or device manufacturer. The testing professional is responsible for using this information and making the required selections and preparation. All devices and systems requiring testing, and all testing criteria, are included in the specification sections for testing, balancing, and commissioning. All testing instruments are calibrated and selected in accordance with ASHRAE Standard 111.2.

Performance verification of a test measurement involves the simultaneous comparison of the actual value using a portable testing device (meter) to the local sensor display, local controller output, and/or the energy monitoring and control system (EMCS) monitor. Ideally, all of these equivalent values are within standard device tolerances. The length of measurement time is to take into account system time delays and the system time constant (this is particularly important when measuring space conditions). Devices considered “failed” are to be retested another time after repair or adjustment. If still failing, replace the device.

4.3.4 Testing Personnel

4.3.4.1 Job Preparation. Efficient testing operations require detailed preparation. To estimate, understand the scope, plan the testing, select equipment, perform the testing, and prepare the reports. This includes preparation of testing and report documentation using project documentation, device performance criteria, test equipment capability, and comparison of actual conditions to required testing conditions.

4.3.4.2 Field Testing. The actual field testing as described in the following sections is performed to check the accuracy and response of the devices and systems required by the design professional. These procedures are detailed to develop a standard method for testing, improve the testing results, and ensure proper operation of the HVAC&R system.

5. DEVICE TESTING—BASIC REQUIREMENTS

5.1 Basic Requirements of Sensors and Devices

5.1.1 Function of Devices. The measurement device detects a specific parameter of the surrounding space or equipment. The signal from the device may be used to control other devices or systems, making device accuracy and performance critical to building operation. Some measurement devices may not be connected to other systems.

5.1.2 Reason for Test. The measurement device is tested to determine its accuracy and intended function. Calibration and adjustment require an accurate test by a reference instrument to determine proper operation. See ASHRAE Standard 111 for information regarding calibration.

5.1.3 Testing Conditions and Requirements. The conditions in the test area are similar to those found under normal operating and stable conditions. The test instrument is located adjacent to the measurement device and experiences the same conditions for an accurate and repeatable test.

5.1.4 Instrumentation. Depending on the use and function of the measurement device, the test instruments are to be selected to measure the same conditions in comparable locations. Different instrument technologies may result in varying response, repeatability, and accuracy to the same conditions. Great care is required to select a test instrument that is at least as accurate as the device to be tested. Proper procedures are to be uniformly applied to produce useful testing results. Instru-
ments that are calibrated as required by their manufacturer must be traceable to an accredited source. See ASHRAE Standard 111 for further information on instrumentation.

5.1.5 Basic Method of Testing/Procedures. After the measurement device and the instrument have been allowed to stabilize in the same space, compare the readings with the project documentation and testing requirements. Record the results. Devices that are deficient in expected performance are to be adjusted or replaced and then retested to ensure proper system performance.

5.1.6 Results and Reporting/Documentation. Each test condition and result are recorded in tabular form to identify the device, location, and result, comparing design with tested conditions. Any deviations from design conditions are to be noted. See Section 9 for documentation details.

5.1.7 Special Conditions and Considerations. Each instrument and control device has its own limitations. Take care to match the instrument accuracy, range, and function to the actual operating conditions, device being verified, and project requirements. Verification should be performed with the system operating within design conditions.

5.2 Air Temperature Sensors

5.2.1 Temperature Sensors—General. Temperature measurements are typically made with resistance temperature detectors (RTDs) and thermistors. RTDs generally have linear characteristics—that is, the resistance changes at a fixed number of ohms for each degree of temperature change. Thermistors have a negative temperature coefficient and have a nonlinear resistance characteristic relative to temperature. This nonlinear characteristic is linearized in the controller or by a separate transducer for a given measurable input to the controller (typically, 0-10 V dc or 4-20 mA) in degrees Fahrenheit or degrees Celsius. The selection of the sensor type, how it is wired and installed (well type and location), the degree of linearization achieved, and the sensor output resolution all affect the total accuracy of the device. When comparing sensor resistance to the temperature readings with the test instrument, care is to be taken to ensure that the correct temperature curve or coefficient is used. For example, two RTDs may both be rated at 200 ohms at 77°F (25°C), but one may change 2.2 ohms per degree and the other may change 1.8 ohms per degree. Similarly, thermistors (and this is particularly true of 10 K ohm thermistors) may be rated with the same resistance at one temperature but be designed to follow different characteristic curves. The installer, control contractor, and person performing the verification tests are to ensure the controller curve is matched to the sensor curve, or errors will occur. While thermistors are rarely used any more, they are noted for the reader’s information.

Often errors are attributed to sensor drift, when the problem is actually that an incorrect sensor characteristic was used either in the controller or by the person performing the test. In some control applications, particularly when the sensor is a great distance from the controller, the output from the temperature sensor is converted to a 4-20 mA signal, and this signal is sent to the controller. In these situations, if there is an error in the temperature readout at the controller, drift in the 4-20 mA transducer is to be investigated as a source of error. Temperature switches that trip at a given set point are also used for limit and status control and/or monitoring applications.

5.2.2 Room Sensors. Location of the room sensor is critical its performance. Its location is not to be subject to loads not related to the average room temperature, such as in sunlight or above heat-producing equipment. Room sensors on outside walls may also produce erroneous readings due to wall transmission. Sensors on internal walls can be affected by airflow in the walls if the area is served with air from a pressurized plenum, such as a pressurized floor or ceiling system. Test instruments are to be located close to the room sensor to experience similar conditions. Drafts (see Figure 1) and high-velocity airflows at the test site are to be avoided.

5.2.3 Duct and Equipment Temperature Sensor. The test instrument is to be adjacent to the duct sensor in the duct or equipment and is to experience the same conditions. Access to the duct or equipment may be provided by an access port or by drilling an appropriate hole in the appropriate location (see Figure 2). All access ports/holes are to be closed after testing. The location of radiant and other heat sources are to be noted and their effects minimized. Temperature conditions in the duct are to be stabilized to the extent possible during the test. Sufficient time is to be allowed in the test procedure for the device and test instrument to stabilize. Due to differences in the device and test instrument capabilities, the stabilization time and performance may differ.

5.2.4 Averaging Temperature Sensor. The test instrument is to be adjacent to the equipment sensor in the equipment and to experience the same conditions. Access to the equipment is to be provided by an access port or by drilling an appropriate hole in the equipment. All access ports/holes are to be closed after testing. Extra care is to be taken when comparing an averaging sensor, such as a coil control tube, with a single-point test device (see Figure 3). This situation may require several test points to determine an average.

Averaging-type duct temperature sensors may have elements that are 25 ft (8.7 m) long or more. Multiple readings along the length of the element or across the duct or coil in traverse fashion are to be made and averaged to compare the temperature read with the actual temperature reported by the controller. A computer control system may be required to bring the averaging element into conformance with the field calibration.

Consideration is given to verifying calibration of averaging elements under different temperature or operating conditions. For example, mixed-air sensors may sense changes in outdoor air temperature that require consideration in varying the sensor offset.

When the readings of several values are near each other, ±4°F (2°C) can be assumed to be of equal importance. If the measured values differ by more than 5°F (3°C), an airflow traverse should be made a: the temperature measurement sites. The comparison of mass flow would provide a weighting factor of flow variations that would provide a better average. One area in cross section with extremely low temperature and proportionally high flow may numerically have a small impact on the average but for mixed air could be a low-enough jet to trip a low-temperature protection switch.
If the duct work is large, one averaging sensor may not be enough to cover the opening. A building automation system (BAS) will then need to average multiple averaging sensors or use the coldest for control. Either way, the prior concern should be used to evaluate what is measured in the field with what is presented by the BAS.

5.2.5 Outdoor Temperature Sensor. The location of an outdoor sensor is critical to its performance. It is not to be in direct sunlight and is to be shielded from the wind and rain (see Figure 4). The test devices are to be in similar conditions and equally affected by airflow and radiant conditions.

When an outdoor air temperature sensor is being used for economizer control, this sensor should reflect the actual temperature entering each unit and may require multiple sensors.

5.3 Pressure Measuring Devices

5.3.1 Special Conditions and Considerations. The testing of control system pressure devices involves the verification of performance and calibration of components that sense and report various pressures in an air-handling, exhaust, or pressurization system. The pressure can be an absolute pressure in relation to a vacuum, a relative pressure in relation to normal atmospheric pressure, or a differential pressure relating two specific pressures, such as on each side of a filter bank.
pressures involved with air measurements are barometric pressure, static pressure, velocity pressure, total pressure, and differential pressure.

Barometric pressure is required to determine air density for correction to standard conditions. Barometric pressures can easily be checked by comparison to a calibrated reference barometer in the same space.

Static pressure devices such as duct pressure sensors can be checked with a water-tube calibrated fluid manometer (verify that the correct fluid is used for the device) or calibrated electronic instruments of comparable accuracy. In systems of moving air in ductwork, measuring pressure at a simple hole in the side of the duct will not produce accurate results due to turbulence and surface friction. Under these conditions, a Pitot tube is used with multiple measurements similar to performing a duct traverse. See ASHRAE Standard 111, for additional information on air pressure measurements. High-pressure systems, such as pressurized tanks, require a calibrated pressure gage. The testing location is carefully selected to ensure that the testing device is experiencing the same conditions but not disturbing the control system device. If these conditions cannot be produced due to physical constraints, then the calibrating device tests proportional conditions in the same system, and the controls are adjusted accordingly to produce the desired results (Example: Height/Head correction when testing a pressure in a pipe that does not have a test port next to the pressure sensor).

Velocity pressures for airflow stations or variable-air-volume (VAV) controllers are verified using a Pitot tube and water/liquid manometer or calibrated electronic instrument. For VAV boxes connected with flexible duct, it is not possible to do an accurate traverse on the flexible duct section due to duct configuration. Solid sections of duct upstream or downstream of the box in limited turbulence areas are preferred for flow verification. If no suitable traverse location is available, the total of the balanced diffuser airflow using a calibrated flow hood or instrument can be used to set the controller proportionally to achieve the desired airflow in the space and report the same volume on the control screen. In situations such as this, several other testing devices can be used to determine air velocity directly in feet per minute or metres per second. These include rotating vane anemometers, thermal (hotwire) anemometers, etc. All of these have advantages and limitations. See ASHRAE Standard 111 for additional information.

Total pressure devices are similar to velocity pressure sensors and are checked in the same way and with the same limitations.

Differential pressure devices for measuring system element pressure drops or space pressurization have many of the same characteristics and problems as the static pressure devices. The testing instrument is to have access to the same conditions without removing or disturbing the active device (see Figure 5). Due to space limitations, the control system device may not have been mounted in a proper or ideal position. Filters are seldom mounted in a position to allow the proper use of a Pitot tube on either side. Space pressurization sensors are particularly vulnerable to error due to door operation. Under these conditions, the testing is performed by personnel who understand the system requirements and measure the pressures as close to operating conditions as possible.

Differential pressure transducers that use flow-through technology cannot be measured or compared with a differential pressure device (e.g., ± digital monomer) tied in the same sensing lines. Under steady-state flow conditions, the same flow probes can be used if the flow-through transducer is removed from the circuit to eliminate the velocity component in the sensing lines. Make a separate duct traverse to eliminate errors in the flow-sensing probe to which the transducer is connected. Ideally, the traverse is performed in a location that represents the airflow being measured by the transducer.

5.3.2 Duct Pressure. The measurement for control of static air pressure in ductwork is used as two separate functions. The failure of a single sensor may result in duct damage, so two independent sensors are used for each function. The first is to prevent overpressurization and damage to the duct system. The second is to control pressure levels to maintain the required system airflow with the most efficient use of energy. Testing can be performed with digital manometers or with mechanical gages. These control sensors and the measurement verification device need to be installed to measure only static pressure sensor and minimize velocity pressure influences on the test instrument.

5.3.3 Building Pressure. Building pressure is measured to allow the control system to maintain a slight positive pressure in the building for ventilation and comfort functions. The pressure differential between inside and outside pressure is very small and is sensitive to many factors. The installed instruments are to be carefully located and have the sensitivity to monitor small pressure changes. Testing instruments need to be equally sensitive and test across the same areas to provide compatibility (see Figure 6). A digital micromanometer setup for differential pressures of the correct accuracy is required for these measurements. Many DDC control systems use a time-averaging algorithm to dampen out wind effect on building pressure controllers. It may be difficult to compare an instantaneous pressure reading with a time-averaged reading, particularly on a windy day. Measuring building pressure in tall buildings can be especially difficult; outdoor air temperatures can create a stack effect in the building. Tall buildings may require multiple building sensors.

5.3.4 Space Pressure. Space pressure is measured to allow the control system to maintain or monitor a pressure difference between two spaces in the building as required by design. Conditions and testing procedures that apply to space pressures are similar to those discussed above for building pressures.

5.3.5 Compressed Air Pressure. Compressed air pressure is measured to allow controls to maintain sufficient air pressure in a storage bank of a compressed air system to operate a pneumatic control system. A calibrated, compatible pressure instrument is used for verification. The test instrument would require a separate and comparable test port to verify a unit-mounted gage.

5.4 Airflow Measurement. An airflow sensor monitors and reports the presence of air velocity and directly measures or calculates the volume or the existence and/or direction of flow at the sensing location. The location of airflow measurement or detection sensors in ductwork may make it impossi-
5.4.1 Duct Flow Stations. Duct flow stations perform airflow measurement on a real-time basis (see Figure 7). The flow measuring station must have turbulent free airflow at the plane of measurement. The testing of these flow stations is usually done by a Pitot tube traverse of the same airstream at a comparable location. See ASHRAE Standard 111 for requirements for Pitot tube traverses. The accuracy and repeatability of the flow station must be evaluated for the locations used.

5.4.2 Terminal Units. Terminal-unit flow sensors are mounted at the terminal inlet duct. Because installation conditions vary, and the terminal control systems have a process for correlating the sensor reading and the actual field flow, it is possible in most cases to adjust the controller reading to the actual conditions (see Figure 8). Actual flow conditions are measured by traverse, or an approximation of the total airflow can be obtained by the sum of all outlets served from that terminal unit with a properly calibrated and applied instrument. This calibration is performed on all terminal units to ensure proper operation.

5.4.3 Switches. Flow switches are used to indicate the existence and sometimes the direction of flow. These can be tested by Pitot tube or by a compatible directional indicator.

5.5 Humidity Sensing Devices. Relative and specific (dewpoint temperature) humidity sensing devices monitor and report percent relative humidity (% RH) or dew-point temperature of the surrounding air or airstream to the connected system. Certain humidity sensors use infrared diffusion technology and report humidity as absolute humidity. To ensure accurate and repeatable readings, verify that the latent and sensible heat of the air at this location has reached equilibrium.

5.5.1 Special Conditions and Considerations. Nearby sources of heat or drafts, such as terminal units, diffusers, windows, cold walls, and the person taking the measurements should be noted and minimized.

The accuracy test for a humidity sensing device depends on the application and expected or specified accuracy for that device. The degree of accuracy required depends on the required precision of the measurement and the extent of the measurement range. If the application requires single-point control only, measurements are made at the control set point. If the application requires measurement and/or control over a wide operational range, two or three measurements are made close to the end points and to the (optional) center of the range for the application. Random tests may be conducted on a small percentage (5% or less) of each application type as a confidence check of the overall system. The percentage is increased in cases where expected performance criteria are high. Humidity sensor performance can also be affected by ambient temperature.

Humidity sensors are to be tested at the ambient temperature where the reading is most critical. For example, a sensor measuring outdoor air temperature for enthalpy economizer functions is to be tested where the enthalpy decision is made, in the range of 50°F to 80°F (10°C to 26.7°C). Avoid testing when outdoor air temperature is above 90°F (32.2°C) or below 40°F (4.4°C).

Failed or out-of-range humidity devices are to be replaced and then be returned to be reconditioned or recalibrated according to the manufacturer's recommendations and agreed-upon conditions.

5.5.2 Room Humidistats. Room humidistats measure the relative humidity at one location in a space. This can be shown as a percentage at the device or reported to a control system. A calibrated humidity testing device placed in close proximity to the room device is the normal method of test (see Figure 9).

5.5.3 Duct Humidistats. Duct humidistats can be single point or averaging devices. Because the portable test instru-
ment is usually a single-point device, it is to experience the same conditions as the tested single-point device or take several readings in the same immediate area as an averaging device.

5.5.4 Enthalpy Sensors. Some control systems use enthalpy or wet-bulb temperature readings in control applications. Enthalpy measuring devices often use a combination of humidity and dry-bulb sensors to calculate enthalpy or wet-bulb temperatures. To field test these devices, the testing professional measures the actual dry-bulb temperature and humidity at the sensor location and then uses a psychrometric chart to determine the accuracy of the device. As noted in Section 5.5, it is best to check the calibration of enthalpy sensors when the ambient temperature is in the range where the enthalpy changeover is likely to occur.

5.6 Quality Devices. Controls for indoor air quality are used to provide alarms or to control air ventilation rate. Because many of these devices are not stable over time, it is important to initially calibrate the device and to require frequent recalibration.

5.6.1 Carbon Dioxide. Carbon dioxide (CO₂) monitors can be mounted in an occupied space, in a return air plenum, or inside an air handler. The level of CO₂ indicates the level of ventilation in an occupied space. If connected to a control system, the CO₂ device will signal for an increase or decrease in outdoor air ventilation. Testing a CO₂ device requires a test meter that is calibrated according to the manufacturer’s instruction and located in close proximity to the device being tested, or testing with a calibrated gas. Operation of controls connected to CO₂ devices may often be verified by adjusting the action limits on an electronic control system and observing the results. Some of the CO₂ standards and reset requirements require the measurement of the CO₂ level exterior to the building. In such cases, the reset calculations are made based on a relative value or on the offset to the outside level.

5.6.2 Carbon Monoxide. Carbon monoxide (CO) devices are often used to monitor the levels of CO in parking garages and other areas with fuel-fired equipment. The output can be used as an alarm or to activate ventilation or exhaust fans. Testing a CO device requires a calibrated test meter located in close proximity to the device being tested, or testing with a calibrated gas. Operation of controls connected to a CO device can often be verified by adjusting the action limits on an electronic control system and observing the results.

5.6.3 Volatile Organic Compounds. Volatile organic compounds (VOCs) are carbon-based gases from chemicals and biological agents that cause allergic reactions or illness in some individuals or may cause unpleasant odors in the occu-
plied zone. A VOC device is sometimes used in conjunction with a CO₂ sensor to control ventilation or, when used with gas-phase filtration, for odor removal. The design and calibration of VOC devices vary widely. When testing VOC devices, closely follow the manufacturer’s instructions.

5.7 Basics of Water-System Devices. Water-system control devices measure the same conditions as the air systems, namely static, velocity, and total and differential pressures. However, because water is noncompressible, it is somewhat easier to test. Most water systems control on an active basis, measuring only static or differential pressures. Water flow rates are usually measured by differential pressures with a venturi or other flow measuring device. The normal testing devices for water systems are dial-type pressure gages, dial-type differential pressure gages, and electronic sensor with or without a read-out device. The installed control devices are to be verified by one of these calibrated test gages to ensure their accuracy.

Simple static pressure dial gages are usually verified by removing them and inserting a calibrated test gage. This works very well on constant-pressure systems. For variable-pressure systems, duplicate ports are required for both gages to be operational at the same time. Similar requirements apply to dial-type installed differential pressure gages. On electronic sensor gages, particularly those without read-out, a test port such as a gage valve or Pete’s plug is to be adjacent to the installed gage. This enables the test gage to sense the pressures and other conditions at the same time, allowing any read-outs or a computer program to achieve the same final reading.

The accuracy test for a water temperature, pressure, flow, or level sensing device depends on the application and expected or specified accuracy for that device. The degree of accuracy required depends on the required precision of the measurement and the extent of the measurement range. If the application requires single-point control only, measurements are to be made at the control set point. If the application requires measurement and/or control over a wide operational range, two or three measurements are to be made close to the end points and (optional) to the center of the range for the application.

The measurement of water quality or water additives is not considered, as this testing is beyond the scope of this guideline.

5.8 Water Temperature Sensors. Water temperature measurements are typically made with resistance temperature detectors (RTDs) and thermistors similar to those used in air temperature measurements, and the same precautions are to be taken to ensure that the sensor, controller, and test readings all use the proper sensor characteristic curve. The selection of the sensor type, how it is wired and installed (wet type and location; see Figure 10), degree of linearization, and sensor output resolution all affect the total accuracy of the device. Temperature switches that trip at a given set point are also used for limit and status control and/or for monitoring applications.

5.9 Water Pressure Sensors. Water pressure measurements are typically defined as either static or differential. Static pressure, or gage pressure, is defined as the difference between water pressure measured at a given point and atmospheric pressure. Differential pressure is defined as the difference in water pressures between two points in a system.

![Figure 10 Water temperature sensor.](image)

(Note: The height of a column of water at a given point is an example of a measure of static pressure. The difference between the inlet and outlet of a pump is an example of differential pressure rise. The difference between the inlet and outlet pressures across a coil, filter, or flow element is an example of a differential pressure drop.)

Mechanical gages and electromechanical transducers are commonly used to measure water system pressure in one of the following pressure units: pounds per square inch (psi), kilopascals (kPa) or feet of water.

The selection of the sensor type, how (and where) it is installed, and the sensor output resolution all affect the total accuracy of the pressure device. Snubbers are sometimes added to dampen system pressure fluctuations. Pressure switches that trip at a given set point are also used for limit and status control or monitoring applications. Typical electromechanical transducers have 0-10 V dc or 4-20 mA output, which can be connected to a direct digital control (DDC) system.

5.10 Water Flow Devices. Water flow rate measurements are typically measured in gallons per minute (litres per second) using pressure-difference type devices (orifice, nozzle, or venturi tube), turbines, Pitot tubes, or electromagnetic or ultrasonic type flowmeters. The selection of flowmeter type is dependent on the application, the accuracy desired, and the cost. Primary applications include energy management (monitoring and metering) and control and system balancing. Flow switches are also available to indicate whether there is a flow or no-flow condition. Typical flowmeter transducers have 0-10 V dc, 4-20 mA pulse output, which can be connected to the DDC system.

5.11 Water Level Devices. Water level in a distribution system, reservoir, or tank generally uses a device measuring the pressure difference between a reference point and atmosphere or by an electromechanical float device (see Figure 11). Both devices can provide a 0-10 V dc or 4-20 mA output signal over
their output ranges. Level switches, which trip at a given set point, are also used for limit and status control or for monitoring applications.

5.12 Basics of Controlled Device Testing

5.12.1 Function of Controlled Devices. Controlled devices include dampers, valves, actuators, and switching devices that perform control operations on air, water, and equipment functions. Correct operation of these devices is critical to the total system operation. Actuators may be considered to include linkages, jackshafts, any transducers and positioners, and the wiring and/or tubing between actuators and the DDC control or pneumatic control devices.

5.12.2 Reason for Test. The controlled devices are tested to determine that they are operable, that the proper signal is being sent to and received by the device, and that the responses are correct.

5.12.3 Testing Conditions and Requirements. The devices and system under test are to be under normal operating and stable conditions.

5.12.4 Instrumentation. The test is to be selected to measure the intended performance, depending on the use and function of the device. The test can be conducted using simple instruments, such as pressure and temperature instruments, or complex digital analyzers, or it may involve simple observation of function.

5.12.5 Method of Testing/Procedures. Access is to be available for the test instrument to read the same conditions as the device under test. This will often require that the location and access around the test ports be compatible with the test instrument.

a. The complete specifications state the degree of detail for which testing is required.

b. Read the result from both devices.

c. Compare the results with the design and testing requirements.

d. Report the results.

5.12.6 Dampers and Valves. Actuators are the primary interface between the control and mechanical system. Actuators may be field installed or integral to other final control devices, such as valves, fire and smoke rated dampers, pitch control in vane axial fans, chiller capacity control, etc. Testing of the function of actuators is a prime concern. Additional procedures, as required by manufacturers, code authorities, or commissioning guidelines, may be required in conjunction with the procedures noted in this guideline.

In some cases, the actuator is an integral part of the valve, and the two are manufactured as a unit. For example, an actuator considered part of a fire and smoke damper is provided to the field as a unit. Fire and smoke codes vary; testing procedures are to follow local codes and NFPA, UL, or other authorities in conjunction with this guideline.

5.12.6.1 Locations. Locations of all dampers, valves, and actuators are indicated in various documents, including control submittal drawings; plans; specifications; and testing, adjusting, and balancing (TAB) documents. To perform these tests, all devices must be physically identified and their correct installation verified.

a. Air handlers may have the following:
   1. Preheat, reheat, and chilled-water valve actuators
   2. Steam heating or humidifier valve actuators
   3. Isolation damper actuators
   4. Inlet guide vane actuators
   5. Outdoor air minimum and economizer damper actuators
   6. Recirculation and exhaust damper actuators
   7. Face and bypass damper actuators
   8. Return air dampers may be found in return air ducts for space pressurization control

b. Chillers and boilers may have the following:
   1. Actuators used for capacity valves or dampers
   2. Combustion dampers
   3. Valves and dampers with safety interlocks may be an integral component of the equipment or part of a specific sequence of operation for start-up and are to be checked by the installing contractor or factory representative using procedures approved by the manufacturer, UL, or other authority in conjunction with this guideline.

4. In all other cases, the dampers and valves are considered integral to their actuators, and their immediate response is included in testing procedures.

c. Cooling towers may have the following:

1. A bypass, isolation, or diverting valves

d. Pumping systems may have a bypass valve, isolation, or diverting valves.

e. Terminal units will have the following:
   1. Damper and valve actuators
   2. The testing modes included here may be used or they may be included in VAV box commissioning methods.

f. Exhaust fans may have local or roof-mounted backdraft or control dampers.
LEVEL 1: Mechanical Installation Observation

1. All components are to be installed in a mechanically sound manner.
2. Manufacturer specifications are to be consulted for conformance to moisture, ambient temperature, and any other limits.
3. Dampers and valves
   3.1 Dampers and valves are to open and close completely, and tight shut-off is to be confirmed for those devices for which it is required.
   3.2 Dampers are to be installed straight and true, level in all planes, and square in all dimensions. Structural support is to be provided as necessary for all multisection dampers. This is to be accomplished using appropriate methods, including U-channel, angle iron, corner angles and bolts, bent galvanized steel stiffeners, sleeve attachments, braces, and building structure. Where the damper manufacturer provides mullion or other internal support for multisection dampers, additional support is to be provided, but only if necessary.
   3.3 Torque is to be distributed evenly along jackshaft and dampers. Any bending of connecting rods or blades is to be corrected.
   3.4 If the actuator is direct over-the-shaft coupled, inspect the actuator connection to the damper shaft. All clamps or setscrews are to be firmly tightened. If hollow shafts are used, check for crushed tubing. Check that the opposite end of the actuator is mechanically attached to a duct or other structure to prevent rotation of the actuator itself.
   3.5 If linkages are used for damper control, all ball joints, connecting rods, support brackets, and any other attachments are to be secure. Verify that jackshafts allow all dampers to open and close completely and operate smoothly. Verify that the ball joints operate freely through their full range of operation and do not bind.
   3.6 Valves are to be installed with proper pipe supports. Reduction from line size is not to exceed two pipe sizes for butterfly or ball valves or one pipe size for globe valves. Elbows close to the valve, and large reductions in line size to accommodate the control valve, are to be noted as possibly reducing capacity.
   3.7 If globe valve rack-and-pinion type linkage is used, the bonnet connection, stem adapters, and actuator connection to the rack and pinion are to be secure.
   3.8 If the actuator is direct coupled to a butterfly or control ball valve, check the clamp or setscrews and connection of the opposite end to the linkage bracket. Check for direct or reverse operation irregularities.
   3.9 If the actuator is located in an area of high temperature (both ambient and conduction through supports), the manufacturer's specifications are to be checked to avoid exceeding limits. Insulation, standoffs, or other methods are used to reduce temperature to below the manufacturer's recommended maximum.
   3.10 If the actuator is located in an area of low temperatures, specifications are to be checked to avoid exceeding limits. Insulation, standoffs, or other methods are to be used to raise temperature to above the manufacturer's recommended minimum.
   3.11 Any condition that may lead to moisture formation and consequent damage or freezing of components or air lines is to be considered.
   3.12 Any condition that may allow physical damage to the actuator is to be corrected.

4. Wiring and tubing connections
   4.1 Verify that wiring and tubing are not subject to physical damage. Conduits are to be firmly supported. Identification of both bundles and individual wires and tubes is to be clear.
   4.2 Connections may not be loose. Always exercise extreme care with electrical conduit. There is the potential for electrical shock.
   4.3 Attachment surfaces may not be subject to high vibration or temperature extremes.
   4.4 Conduits may not pass through cold areas and back into warm areas, allowing condensation to form and drip into actuators, transducers, positioners, or other devices. The presence of drip loops, air passage stops, or the rerouting of conduits may be necessary.
   4.5 Pneumatic tubing air leaks are to be identified by manually setting pressure at maximum allowable for five minutes without reduction of pressure.

LEVEL 2: Operational/Functional Testing

The following checks are to be made with the equipment operating to verify interaction, operation, and control ranges of the various control devices. During this testing, observe the effects of vibration or any other outside influences that affect the operation of the equipment.

1. Transducers and positioners are to be installed and checked per the manufacturer's instructions. Resolution and repeatability are to be within design specifications. Recommissioning and recalibration at regular intervals is recommended. (Note: If open-loop control is used, positioners are required.)

2. Dampers and valves
   2.1 All actuation is to be tested for conformance to the project specification, including, but not limited to, direct or reverse operation, spring-return function in correct direction (when applicable), full close-off of tight-fit dampers, full rotation or stroke of valves, and all other specified operations sequences.
   2.2 If multiple actuators are operating the same valve, damper, assembly, or jackshaft, they are to start and end their rotation or stroke simultaneously.
   2.3 If actuators are operating in parallel from the same signal and are located on different dampers, verify that all dampers are to start and stop simultaneously.
or lead/lag as required. If valves or dampers are being sequenced, the first stage is to open or close completely before the second stage starts to move, or lead/lag as required. Multiple valve or damper actuators served from one transducer are to be coordinated to provide the proper positioning. (Note: The use of one pneumatic pilot positioner’s output to feed more than one actuator is poor practice.)

2.4 Operate damper and valve actuators through full range, several times, in each direction. Smooth movement at nearly constant speed is expected without any binding or hesitation, sudden jumps, noise, or other problems.

2.5 Due to dynamic forces, the dampers or valves may be pushed out of correct position. A minor deviation may be acceptable without operation of the positioner to correct. However, these devices are still required to maintain their set point and be able to provide full-open and full-closed position.

2.6 Hysteresis is to be tested after placing the controlled device in the middle position. The signal is first run to maximum, and the actuator is allowed to reach the end position. Midpoint signal is again given, and the actuator is observed. A mark on the stem or other surface is used to note variation to positioning. The process is repeated after moving to the minimum position. Minor variations may be acceptable.

2.7 Actuation dead-band may be determined by increasing the signal to the controlled device manually in small increments until the actuator moves. The difference between the initial and movement signal is the actuation deadband. Actuation deadband, while more prevalent in pneumatic systems, is still possible with electric, electronic, or DDC systems. The test is to be repeated at the start, midpoint, and near endpoint of damper travel.

2.8 Electronic actuators (2-10 V dc, 4-20 mA, or 4-20 mV) are usually inherently positive positioning and are to be checked to verify accuracy as intended.

2.9 If a damper or valve is of the modulating type, command a midpoint signal input to the actuator and verify that the device is approximately half open.

2.10 If fail-safe operation is required, remove power and observe the damper or valve return to the failsafe position.

2.11 Test as appropriate; include auxiliary functions such as position indication, safety interlocks, or switching for the purposes of starting another function.

LEVEL 3: Performance/Total System Function Testing

Control loops control devices using comparative feedback. The rate comparison and adjustment is tuned by manipulating the proportional, integral, or derivative (PID) gains and adjusting other factors or constants. Typically, HVAC loops do not use the derivative gain. Using common language, the loop is discussed or labeled as the “PI loop.”

1. Each control loop is to be examined throughout its full range of operation and in each of the modes of operation. Step changes are introduced to observe response and stable operation. Other potentially interacting loops are to be active and allowed to interact with the loop under test.

2. The system, actuators, and other functions, if appropriate, are to be tested for stable operation throughout its operating range. Testing is performed under different load conditions as appropriate. For example, temperature control loops should be tested to observe the valve/damper throughout its range of operation by varying the load. The systems are to be tested during start-up as well as unoccupied and occupied modes.

3. Retuning of loops in conjunction with other loops may be required. For example, the mixed-air-temperature loop may cause changes in the quantity of airflow and interact with the static pressure control loop. Both the mixed air and static pressure loops are to be adjusted to produce efficient system interaction.

4. Dampers and valves

4.1 Operate actuators from minimum to maximum position and vice versa. Verify that operation is without any binding or hesitation.

4.2 Multiple actuators operating from the same output are to move in coordination.

4.3 When a single actuator operates multiple dampers/valves, the linkages should allow full rotation or extension of the shaft, stem, or crank arm throughout the full operating range.

4.4 When failsafe operation of dampers or valves is required, remove power and observe the return to failsafe position. (Note: When batteries provide power for failsafe function, verify that a failed battery alarm is installed and functioning.)

4.5 All auxiliary switching devices and systems are to be tested.

4.5.1 All auxiliary switching devices and systems that are related to life safety and critical equipment safety are to be verified with the appropriate responsible entity. Examples include smoke systems, gas flame safeguard or combustion interlocks, and flow switches.

4.6 When testing is complete, all safeties, overrides, manual releases, manual positioners, and any other bypass are to be returned to the automatic position unless the system is not ready and operation or safety would be compromised.

5. Operational checkout: Transducers, positioners, and actuators are to be observed for dithering (rapid oscillation), hunting (failure to reach steady state), or an extremely slow response. The causes of these problems are usually poor parameters, failure to tune loops, interference from another part of the system, or physical and/or electronic malfunction of the equipment.

5.1 If no visual indication is given, very small dithering can still exist, and the following checks will verify and isolate the source.
a. Check the signal at the input to the actuator with a fixed command. If the signal is fluttering, move back to the next component in the chain of signals. Check the output at this device to determine the source. If the fluttering is present at these input terminals, move back to a prior device.

b. If the source of interference is not in the field devices, then check the connections. Loose terminals or wire connections will often vibrate and cause dithering. Unfiltered, unregulated power supplies can cause dithering in the order of 1 Vole or 10% of the full range. Loose pneumatic pipe fittings will cause slow leaks with extra corrections every few minutes.

6. Loop tuning checkout: The tests below are to be repeated at the start, midpoint, and near endpoint of damper or valve travel.

6.1 Near the closed position, decrease the control signal until movement is detected. Then slowly increase the control signal by minimum steps in the manual mode until the actuator moves. The difference between the lowest signal and the highest signal creating movement is the actuation dead-band. Observe and note the following for reference at all three test positions.

a. A disturbance or step change is to be introduced into the system. If a manual or mechanical override exists, the damper or valve actuator position may be changed. (Example: A change in temperature set point of several degrees is the typical means. This causes the loop to recalculate the signal and reposition the actuator to come back to set point. Observe the results and note the time between oscillations, the number of oscillations, and the approximate amount of actuator movement with each oscillation.)

b. Continued oscillation, increased movement with each oscillation, or failure to move at all indicates a need for tuning. During testing, be aware of other disturbances that may occur and cause corrections that extend the number of oscillations or the duration of the return to steady state.

c. During start-up, loops may not function properly. The loop may have fuzzy logic statements or limits preventing fast opening or closing. (Examples: Condensation in a coil or heat exchanger, boiler or chiller response, or other system issues may be occurring and influencing the testing.)

6.2 The above tests are to be performed at the three positions because the nonlinear characteristics of valves and dampers may allow constants that work well at one portion of the curve to fail totally at another.

a. A loop tuned at one set of conditions may not operate properly at another. Loops are to be tuned initially and retuned again during the opposite season of the year. (Example: Mixed-air control responds with a small change when the outdoor air temperature is near set point and with a very large change when it is very cold outside.)

b. Self-tuning loops are to be tested the same as the manually tuned loop as described above. A well-tuned control loop will reach a steady state with declining amplitude and a minimum number of oscillations. (Note: Tuning of loops is a difficult and poorly understood process but critical to good control and long life of actuators and peripheral components. Self-tuning loops may be predisposed to a learning curve and may not react properly when the system requires an unanticipated change. Many facilities operate 24 hours. The response time on a return from an unplanned shutdown may be very slow, requiring the self-tuning function be disabled during start-up.)

c. The values found in the testing are to be given to the control contractor for use in retuning the loops. It is to be emphasized that tuning may require watching the actual process or control device as parameters are changed, because scan times and temperature sensor change lags may appear as steady values on a computer screen, while constant oscillation is occurring at the final field device.

7. Sequence of operation: All actuators and their connected devices are to perform according to the sequence of operation requirements.

5.13 Output Devices. Output devices are generally used to control motors or other equipment based on parameters monitored by the output device. Some of these devices include variable-frequency drives (VFDs) for motor speed control, freeze stats for coil protection, smoke detectors for emergency shutdown, and other related devices.

Testing of output devices involves the inspection of the installation to ensure that the device monitors the appropriate parameters and controls the correct function or equipment. The input parameters, such as pressures, temperatures, or presence of smoke, are verified by changing the conditions to produce a device or equipment response.

5.13.1 Variable Frequency Drive. VFDs are used to control the speed of motors on pumps and air handlers to match load conditions and to save energy. Generally, these devices receive a signal from a pressure sensor in the water or air system that causes the VFDs to increase or decrease the motor speed to match the pressure set point. The pressure sensor is tested first and calibrated to ensure that the correct signal (usually as 2-10 Vdc or 4-20 mA) is being sent. The response of the VFD to changes in the set point is the normal testing function. Response time and system stability during these changes are also critical to proper system operation.
5.13.2 Low-Temperature Limit. This safety device is commonly referred to as a "freeze-stat," "mixed-air low limit" or "low-temperature cutout." These devices generally include a pressurized tube that monitors the input conditions at a water coil. The sensor tube is installed across the surface of the coil (see Figure 12). Under temperature conditions below the set point but above 32°F (0°C) along any 1 ft (0.3 m) of the element, the low-temperature cutout switch will trip and shut down the fan or initiate other safety control functions to protect the coil from freezing.

Testing can be performed by freezing a foot or more of the sensor tube with ice or a can of compressed gas. The 1 ft (0.3 m) section to be tested is to be near the far end of the capillary, because a kink in the sensing element may render a portion of the tube inoperative. However, because most low-temperature cutouts are designed to fail open (shutting down the air handler) if the tube fails, activating the device manually will also check the control function, provided that the tubing is not kinked. The set point of the device at 38°F (3.3°C) or higher is to be compatible with the air-handler system location, function, and local practice.

5.13.3 Smoke Detectors. Smoke detectors are generally required by code in the supply-air side for all air handlers over 2000 cfm (944 L/s) and in the supply and return sides for units over 15,000 cfm (7080 L/s). These devices are designed to shut down the air handler to prevent the unwanted circulation of smoke. They can be single-point devices, as in a ceiling mounted smoke detector, or include a collection tube extending across the duct or air handler (see Figure 13). Test activation can be accomplished with test smoke from a can or a smoke generator. Smoke generators may overload the device, making it difficult to reset and restart the air handler. Some smoke detectors have test initiation buttons that allow testing of the shutdown function without injecting smoke.

These tests are most often performed in cooperation with the fire alarm contractor to verify the interface with the fire alarm system.

5.14 Electrical Testing. Electrical testing is performed to verify the correct amperage and voltage serving the mechanical equipment. Motors rely on correct voltage and on the amperage operating within the design range, as indicated on the motor nameplate. Voltage variation between phases is common but is not to be more than 3%. Motors drawing amperage above the maximum nameplate rating of the motor may quickly burn out. Thus, both constant-volume and variable-volume systems are to be tested at maximum capacities. The fan airflow or pump water flow is to be reduced if necessary to cause the motor to operate at or below nameplate amperage. Three-phase motors are to also maintain all three phases of power to prevent single phasing, which will quickly burn out the motor. When a motor loses one phase, one of the other phases will try to pick up the load and thus nearly double in amperage. If a phase is lost, the motor is to be shut down immediately. Most motor starters and frequency drives have built-in safeties to prevent this condition.

Testing is performed with calibrated portable voltage and amperage meters. The test readings are compared to design and motor nameplate requirements to determine acceptability.

Electric control systems require power to operate the central and distributed controller as well as many of the devices. Correct and reliable voltage is critical to the operation of the controls. It is often necessary to have the control system connected to the emergency power system. This condition is to be verified by power outage and the system recovery tested when appropriate.

5.15 Rotating Equipment Testing. Testing of rotating equipment is performed with a calibrated tachometer or strobe light.
Tachometers can be a direct-contact type when the shaft end is accessible and has a center location hole, or a photo type that responds to reflected light from a piece of reflector tape applied to the shaft or sheave. Care is to be taken in contact readings to obtain a firm contact connection. Photo and timing light readings are also subject to errors in multiples of actual rpm caused by poor lighting or procedures.

Rotating equipment testing is performed on motors, pumps, and fans to determine their operating conditions and compare those with the design and submittal data. Motors used in air-conditioning equipment usually operate at an approximate speed of 1750 or 3600 rpm. Some small fans operate at approximately 1050 rpm. Determination of the motor operating conditions verifies the correct motor installation and operation. Because most pumps are directly connected to the motor, the rotational speeds are the same, and the pump rpm can be compared to the pump curve for volume determination.

Fan rpm is used to compare operating conditions to fan design data. This analysis can provide answers and correction factors to nonperforming fans. Both fan and motor rpm are required along with sheave sizes and motor actual and maximum amperages for the calculation of new sheave sizes to correct fan performance where necessary.

It is not uncommon to encounter a VFD operating a direct drive fan or pump at speeds greater than 50 Hz. Care should be taken to review the equipment submittal to determine the design rpm. When a motor is driven above 60 Hz, the motor nameplate amperage is still a limiting factor and is not to be exceeded. Typically, motors are safe to operate below two times the nameplate rpm. When equipment submittal data are not available, it is advisable to obtain permission from the motor manufacturer before operating a motor above nameplate rpm. Each fan and pump has a critical or maximum operating speed that is not to be exceeded; when these data are not available, contact the equipment manufacturer.

6. SYSTEM COMPONENT TESTING

6.1 Basics of System Component Testing. Testing connected systems of mechanical equipment and sensors verifies the performance of the system and the correct and accurate operation of the sensors. The system testing verifies equipment performance to the sequence of operation specified. In addition to the individual device testing described in Section 5, the sequences are to be verified for all normal conditions and reported on the appropriate forms.

6.2 Air-Terminal Units

6.2.1 Operation. The equipment and controls are to be in operation before the start of testing.

6.2.2 Basic Procedures. Before testing or adjusting any terminal unit (box), verify that adequate flow and pressure are available. Make system adjustments as necessary, or investigate problems that prevent successful completion of the procedures and report any deficiencies. Boxes are to have enough flow to obtain the maximum set point with the damper under control (not 100% open). For direct digital control systems that require a box autozero procedure, run the autozero before beginning the testing. Ideally, the autozero of the flow transducer is obtained with the central air-handling unit (AHU) fan OFF. However, some VAV controllers perform an autozero by isolating the flow sensor from the pick-up tubes. These controllers can perform the autozero routine with the AHU fan ON or OFF.

Based on the manufacturer’s recommendations, set the controls to obtain the design cfm (L/s) in each mode of operation as described below. Record final set points on report forms, including area factors and calibration factors. For pneumatic pressure independent controls, the controller setting may require minor adjustments to obtain the design cfm (L/s). Cycle the thermostat to ensure that new set points will repeat. Flow at box velocity sensors are to be within original equipment manufacturer’s specifications.

Performing traverses for area coefficient (Ak) verification is a requirement. Additional traverses are performed when the air distribution cannot be measured or when the air distribution measurement is suspect. Box airflow sensor ΔP measurements are only used in these procedures as a last resort when traverses cannot be performed.

6.2.3 Box Adjustment Procedures for Pressure Independent Boxes

6.2.3.1 Single-Duct Variable Air Volume (see Figure 14)
a. Operate the controls for the maximum flow, and verify the box control action.
b. Verify maximum flow, make adjustments to obtain the design cfm (L/s). Record the final cfm of downstream air distribution. (Note: Record any airflow correction factor applied to a DDC controller.)
c. Adjust the controls to obtain minimum flow. (Note: Some box control systems require setting the minimum flow before setting the maximum flow.)
d. Verify minimum flow at downstream air distribution. (Note: Record any airflow correction factor applied to a DDC controller.)
e. If the terminal unit has a reheat coil, verify the proper valve or controller size and proper control sequence. If a separate heating airflow is specified, measure, adjust, and record the readings and settings for the heating airflow. (Note: Confirm that electric heating cannot be activated if there is no primary airflow.)
6.2.3.2 Dual-Duct Variable Air Volume (see Figure 15)

a. Operate the controls to simulate full cooling. (Note: May need to close the hot deck damper.)

b. Verify the proportional balance of the downstream air distribution.

c. Adjust the controls to obtain cooling maximum flow, as required by the design, and record.

d. Record any airflow correction factor applied to a DDC controller.

e. Operate the controls to simulate the cooling minimum. (Note: May need to close the cold deck damper.)

f. Operate the controls to simulate heating minimum. (Note: May need to close the cold deck damper.)

g. Adjust the controls to obtain the heating maximum flow to design, and record.

h. Record any airflow correction factor applied to a DDC controller.

i. Operate the controls to simulate for the heating minimum. (Note: May need to close the cold deck damper.)

j. Verify damper control-box sequence and airflow to ensure proper operation and flow delivery over the operating range of the box.

k. Test hot and cold duct dampers for proper closure by the temperature method, which includes measuring the before and after box temperatures in full cooling and in full heating.

6.2.3.3 Constant-Volume, Dual-Duct, Single or Dual Controller (see Figure 16)

a. Operate the control to simulate full cooling. (Note: Hot-deck damper should be in the closed position.)

b. Verify the proportional balance of the downstream air distribution.

c. Adjust the controls to obtain cooling maximum flow as required by the design, and record.

d. Operate the control to simulate full heating. (Note: Cold-deck damper should be in the closed position.)

e. Adjust the controls to obtain heating maximum flow as required by the design and record.

f. Verify that the cfm (L/s) remains constant over the range of operation and that the control sequence is correct. If unable to verify, write up the problem as a deficiency.

g. Test hot and cold duct dampers for proper closure by the temperature method.

6.2.3.4 Parallel Fan-Powered Variable-Air-Volume Box (see Figure 17)

a. Operate the controls to obtain maximum cooling flow, and verify the action of the box controls. Verify that the box backdraft damper closes and that no primary air is leaking out of the filter box fan section.

b. Verify the proportional balance of the downstream air distribution.

c. Adjust the controls to obtain cooling maximum flow, as required by the design, and record.

d. Record any airflow correction factor applied to a DDC controller.

e. Adjust the controls to obtain the minimum primary flow and heat.

f. De-energize the parallel fan, and adjust the controls to obtain the minimum primary flow to the design flow by summation at air distribution, and record. (Note: The box velocity pressure taps may be used to set the minimum flow if verified as accurate during Step 5 (Section 6.2.3.4[e]) but only if the velocity pressure is greater than 0.03 in. of water [7.47 Pa]).

g. Record any airflow correction factor applied to the DDC controller.

h. Energize the fan and close the primary air damper. Adjust fan airflow to obtain fan design flow.

i. If the terminal unit has a reheat coil, verify the proper valve or controller size and proper control sequence. (Note: Confirm that electric heating cannot be activated if there is no fan airflow.)

j. If the coil is a multistage electric type, verify that the stages sequence properly. Read the amperage and voltage during full heat if the coil is electric.

k. Balance the water coil if the reheat coil is hydronic. Record water flow gpm, entering air temperature, leaving air temperature, entering water temperature, and leaving water temperature.

l. Confirm unoccupied operation as specified. For example, check that the fan and heat cycle at the appropriate zone temperature with the primary air damper closed.

m. Re-energize the parallel fan, set the fan cfm (L/s) to design flow, and record the fan cfm. Subtract the minimum primary air cfm from the total of the air distribution to determine fan cfm. Adjust the parallel fan speed/airflow prior to testing the heating mode, especially on electric reheat boxes, to ensure that the heater safeties (i.e., flow switches, high limits) are not preventing heater operation.

n. Verify that the fan energizes at the appropriate time and in the proper sequence.
6.2.3.5 Series Fan-Powered Box (see Figure 18)

a. Operate the controls to close the primary air damper.
b. Verify the proportional balance of the downstream air distribution.
c. Adjust the fan cfm (L/s) by adjusting the fan speed to obtain the design flow.
d. Set the box damper controls and adjust as necessary to obtain the maximum required primary airflow (from the air handler) to match the fan airflow. This condition results in a neutral condition with no air coming in or out of the box plenum opening. If access to the return inlet is not possible, then test for return air leakage by the temperature mixture method. If neutral conditions do not exist, adjust the fan speed to obtain neutral airflow.
e. Recheck the air distribution, and record the final fan cfm (L/s).
f. Record any airflow calibration/correct factor applied to the DDC controller.
g. Adjust the heat controls and set the minimum primary airflow by using the box’s primary air inlet flow sensor differential pressure (ΔP). Record inlet flow sensor ΔP. Record the final minimum primary flow. Record any airflow correction factor applied to the DDC controller.
h. If the terminal unit has a reheat coil, check for the proper valve or controller size and the correct control sequence. Balance the water coil if the reheat coil is hydronic. If the coil is a multistage electric type, verify that the stages sequence properly. Read amperage and voltage during full heat if the coil is electric. Record the inlet and outlet air temperatures, and verify the coils actual MBtu/h (kW/h).
i. If unoccupied heating mode is specified or available, verify that the primary air damper closes and that the fan and heat cycle maintain the unoccupied zone temperature set point.

6.3 Air Systems

6.3.1 Single-Zone Systems. This procedure applies to all constant-volume systems that have a single-zone control per air-handling unit.

6.3.1.1 Operation. All equipment and controls in the system are installed and operational before the testing, adjusting, and balancing (TAB) technician begins the procedure.

6.3.1.2 Procedures

a. Measure the airflow quantity of the supply, return, and outdoor air by Pitot tube traverse, unless it is impossible to do so.
b. When the air quantity cannot be obtained by Pitot tube traverse, then use the sum of the outlet or inlet quantities as the total cfm (L/s) of the fan. If a Pitot tube traverse is not performed, then note the reason on the TAB report.
c. Proportionally balance the air distribution systems. Verify that at least one outlet or inlet damper is fully open on every branch duct and at least one branch-duct balancing damper is fully open.
d. Adjust the fan speed to obtain 100% to 110% of design airflow, and verify the minimum outside airflow, if required.
e. Record the final measurements of the air distribution.
f. Set the system in normal mode and record the following final conditions:

1. Supply, return, and outdoor air quantity
2. Motor voltage, current, kilowatts, and actual motor speed
3. Fan speed
4. Static pressure profile, including the inlet and outlet external static pressures
5. Coil capacity test results (including outside and return air temperatures)
g. If the system is equipped with an economizer, then repeat the data in Step 6 (Section 6.3.1.2[e]) in the economizer mode. (Coil capacity tests need not be repeated if the coils are not pertinent to the economizer mode.) Confirm that the economizer mode is enabled and disabled at the designated and appropriate enthalpy or temperature conditions.
h. For units with economizer control, confirm that the outdoor air damper returns to its minimum position at appropriate temperature (enthalpy) level. Confirm that the damper positions are in the same minimum position whether opening on startup or closing from maximum position on economizer lockout.
i. For units with demand control ventilation, confirm the override of the outdoor air damper control on demand for ventilation.

6.3.1.3 Report

a. Include all test data on the appropriate data sheet forms.
b. List any uncorrected deficiencies that affect the test results on the deficiency form and include it with the report.
c. Include the report contents procedure requirements and all device test reports.

6.3.2 Multizone Systems

6.3.2.1 Operation. All equipment and controls in the system are installed and operational before the TAB technician begins the procedure.

6.3.2.2 Procedures

a. Measure the total airflow quantity of supply, return, and outdoor air by Pitot tube traverse for each zone, unless it is impossible to do so.
b. When the quantity cannot be obtained by Pitot tube traverse, use the sum of the outlet quantities as the total cfm (L/s) of the zones. If a Pitot tube traverse is not performed, then note the reason why on the TAB report.
c. Proportionally balance the supply outlets in each zone.
d. Proportionally balance each supply zone.
e. Proportionally balance the return air system.
f. Set the fan speed to obtain 100% to 110% of design airflow, and adjust the minimum outdoor airflow, if required.
g. Measure final data with the zone dampers in full cooling mode, and repeat in full heating or bypass mode.
h. Test the zone temperature control mixing dampers for proper shut-off of both hot and cold decks, and report the percentage of leakage.
i. Verify that all zone mixing dampers are controlled by the proper space thermostat or sensor.
j. Confirm that the appropriate reset of hot and cold duct temperature set points based on zone demand has occurred.
k. If the system is equipped with an economizer, then repeat the data in Step 6 (Section 6.3.2.2[f]) in the economizer mode. (Coil capacity tests need not be repeated if the coils are not pertinent to the economizer mode.) Confirm that the economizer mode is enabled and disabled at the designated and appropriate enthalpy or temperature conditions.
l. For units with economizer control, confirm that the outdoor air damper returns to the minimum position at the appropriate temperature (enthalpy) level. Confirm that damper positions are at the same minimum position whether they are opening on startup or closing from maximum position on economizer lockout.
m. For units with demand control ventilation, confirm that the override of the outdoor air damper control has occurred on demand for ventilation.
n. At the completion of the balancing, set the system to automatic. If the system is equipped with an economizer, then data are also to be recorded in the economizer mode. (Coil capacity tests unrelated to the economizer need not be repeated.) Record the following final conditions:

1. Supply, return, and outdoor air quantity
2. Hot and cold duct temperatures
3. Motor, voltage, current, kilowatts, actual motor speed
4. Fan speed
5. Static pressure profile (including a static pressure in each zone)

6.3.2.3 Report

a. Include all test data on the appropriate data forms.
b. List any uncorrected deficiencies that affect the test results on the deficiency form and include this information with the report.
c. Include the report contents procedure requirements and all device test reports.

6.3.3 Single-Duct, Variable-Volume, Pressure Independent Systems Operation. All equipment and controls in the system are to be in operation before the TAB technician begins the procedure.

6.3.3.1 Procedures

a. Set each terminal box according to the appropriate procedure given in the component section for VAV box testing. If there is diversity between the total box design airflow and the fan's design airflow, the system may need to be manipulated to provide the required airflow to the farthest or most difficult to satisfy terminal. System manipulation may include setting boxes to heating, overriding box dampers closed, or increasing the system static pressure set point.
b. After individual terminal set-up is completed, the next step is to determine the system static pressure set point. Command all the terminals to their maximum airflow set point. If the system has diversity, close the appropriate ter-
minal dampers, nearest to the fan, simulating the fan design airflow. Next, verify all of the box damper positions. Increase or decrease the static pressure set point so that all terminals airflow set points can be satisfied. Record the static pressure set point and the location of the boxes most difficult to supply.

c. Proportionally balance the return air system.

d. Determine the final total airflow quantity of supply, return, and outdoor air by a Pitot tube traverse unless it is impossible to do so.

e. Where the quantity cannot be determined by a Pitot tube traverse, use the sum of all low-pressure terminals as the total cfm (L/s) of the fan. If a Pitot tube traverse is not performed, note the reason why on the TAB report.

f. With the system set for diversity, record the following final conditions:
   1. Supply, return, and outdoor air quantity
   2. Motor, voltage, current, kilowatts, and actual motor speed
   3. Fan speed
   4. Static pressure profile, including the pressure at the static sensor
   5. Coil capacity tests
      
      (Note: Verify that the fan motor operates at acceptable amperage and voltage with all terminals fully open.)

g. If the system is equipped with an economizer, repeat the data in (f) above in the economizer mode. (Coil capacity tests need not be repeated if the coils are not pertinent to the economizer mode.)

6.3.3.2 Report

a. Include all test data on the appropriate data sheet forms.

b. List any uncorrected deficiencies that affect the test results on the deficiency form, and include this information with the report.

c. Include the report contents procedure requirements and all device test reports.

6.3.4 Air Systems—Testing the Humidity Control System. A humidity sensor connected to a building automation system (BAS) or direct digital control (DDC) system controls a humidifier or dehumidifier to maintain the space ambient or duct airstream at a specified moisture condition.

Verification of the specified humidity system operation involves comparing the system controller set point to the system control point measured at the humidity sensing device under steady-state operating conditions. Unstable or steady-state control that does not meet the specified humidity operating parameters may require a review and change of the system control gains, system components, or both.

6.3.5 Water-Terminal Units. Water-terminal units include fan-coil units, induction units, unit heaters, fin-tube radiation, reheat coils, etc.

6.3.5.1 Operation. All terminal devices and connected systems are to be in operation before the TAB technician begins the balancing procedure. All controls are to be installed, calibrated, and fully operational.

6.3.5.2 Report

a. Include all appropriate test data on approved water balance data sheets as required in the water systems contents procedure.

b. In the conclusion, list both the conditions at the time of the test and the results.

c. List any uncorrected deficiencies that affect the test results.

6.4 Testing Water Systems Control

6.4.1 Operation. All equipment and components in the system are to be in operation before the technician begins the procedure. All controls are to be installed, calibrated, and fully operational. (Note: Verify that the water cleanliness is acceptable to the responsible party, the strainers are clean, and the system has been vented.)

6.4.2 Primary Constant-Flow Systems

6.4.2.1 Procedures

a. Perform the shut-off head-pressure test on each pump to determine the impeller size and pump operating curve.

b. Make the initial setting of pump flow at approximately 110% of design flow, with all system coil control and balance valves in the wide-open position and the bypass control valve closed.

c. Follow one or the other of the following steps as appropriate:
   1. If the balance valves are manual, proportionally balance the flow through each coil or element in the system. Make as many passes as required to obtain a proportional balance.

   2. If the system uses automatic flow control/balance valves, verify that the correct valve has been installed in each application. Measure the differential pressure across each valve to ensure that the system pressure allows all flow control/balance valves to operate within their rated minimum and maximum differential pressure.

   d. If three-way valves are present at each coil/heat exchanger, cycle the controls to modulate the valve to bypass after setting the coil flow, and set the flow through the bypass to match the coil flow.

e. Make a final adjustment at the pump, if necessary, to obtain 100% to 110% of design flow. If this flow is not attainable, make note of the reason for the deviation.

f. Perform a final pass through each coil/heat exchanger, recording the final flows and pressure drops.

g. Record all final pump operating heads and flows, including shut-off head and impeller size.

h. Measure and record the amperage and voltage on all pumps before and after the system balancing.

i. Measure and record the system operating pressure at the control point, with all valves in the system at full flow through the coils/heat exchangers. Compare the coil/heat exchanger flow totals to the pump gpm, and investigate any discrepancy.

j. Measure and record the total system flow at full bypass. Record the control pressure operating point.

k. Upon completion of TAB, record the following data on appropriate report forms:
1. Design water flow, gpm (L/s)
2. Design pressure criteria
3. All nameplate data
4. Amperage and voltage measurements
5. Pump kilowatts or horsepower, actual and design
6. Design pump and motor rpm
7. Actual motor rpm (if accessible)
8. Actual pump rpm if different from the motor rpm
9. Pump shut-off head pressure
10. Pump operating head pressure
11. Pump suction pressure (both operating and shut-off)
12. Pump discharge pressure (both operating and shut-off)
13. Position of the balancing valve at the final balance
14. Actual water flow gpm (L/s)
15. Actual pressure measurements at the flow elements, coils, etc.
16. Actual bypass pressure and control setting at the final balance (if installed)

6.4.2.2 Report

a. Include all test data on approved water balance data sheets as described in the report contents procedure.
b. In the conclusion, list both the conditions at the time of the test and the results.
c. List any uncorrected deficiencies that affect the test results.

6.4.3 Constant-Flow Primary/Variable-Flow Secondary Systems

6.4.3.1 Procedures

a. Perform a shut-off head pressure test on each primary and secondary pump to determine the impeller size and pump operating curve.
b. With all system valves in the wide-open position, set the primary and secondary pump operating head at approximately 110% of design flow.
c. Balance the water flow in the primary loop to 100% to 110%. Balance the flow between the primary elements (chillers, boilers, etc.) if there is more than one element per pump.
d. With all control and balance valves open, balance the secondary pumps and flow to 110% of design flow. If the secondary loop system includes variable-speed drives controlled by a differential pressure sensor, set the initial pressure necessary to control the pumps. A good starting point for this setting is 5 psi (34.5 kPa) above the design pressure drop on the highest-pressure-drop coils. This pressure may need to be adjusted higher during the testing operation to provide design flow to all coils.
e. Follow one of the following steps as appropriate:
   1. If the balance valves are manual, and if there is no diversity in the secondary system, proportionally balance the system. Make as many passes as required to obtain a proportional balance. **Note:** If there is diversity in the secondary system, select enough coils to match the secondary pump design gpm (L/s) while closing the remaining valves. Proportionally balance the flow through the selected valves as indicated above. Once the system has been proportionally balanced, select enough open valves to match the diversity and close them. Balance the flow at the newly opened valves. Record the coil numbers and locations necessary to produce the diversity readings.)
2. If the system uses automatic flow control/balance valves, verify that the correct valve has been installed in each application. Measure the differential pressure across each valve to ensure that the system pressure allows all flow control/balance valves to operate within their rated minimum and maximum differential pressure.

f. Make final adjustments at the pumps to obtain 100% to 110% flow. If this flow is not obtainable, make note of the reason for the deviation.
g. Perform a final pass through the primary and secondary components, recording final flow and pressure drops with the system set for diversity as described above, if applicable.
h. Record all final pump operating heads and flows.
i. With the system set at maximum flow, ensure that there is proper flow direction at the primary/secondary bridge. Verify temperatures in the primary and secondary loops to ensure there is no mixing of secondary return at full cooling.
j. Record the actual pressure at the control point for the variable-volume secondary system. Compare this to the actual control device readout or set point.
k. Set the pump control of the secondary system at minimum flow.
l. Measure and record the power on all pumps before and after the system balancing.
m. Upon completion of the TAB procedure, record the following data on the appropriate report forms.
   1. Design water flow, gpm (L/s)
   2. Design pressure criteria
   3. All nameplate data
   4. Power measurements
   5. Pump kilowatts, actual and design
   6. Design pump and motor rpm
   7. Actual motor rpm (if accessible)
   8. Actual pump rpm if different from the motor rpm
   9. Pump shut-off head pressure
   10. Pump operating head pressure
   11. Pump suction pressure (both operating and shut-off)
   12. Pump discharge pressure (both operating and shut-off)
   13. Position of the balancing valve at the final balance
   14. Actual water flow gpm (L/s)
   15. Actual pressure measurements at the flow elements, coils, etc.
   16. Actual bypass pressure and control setting at the final balance (if installed)

6.4.3.2 Report

a. Include all test data on approved water balance distribution equipment data sheets as required by the report contents procedure in Section 6.
b. In the conclusion, list the conditions at the time of the test and the results.

c. List any uncorrected deficiencies that affect the test results.

6.4.4 Testing Water-System Control. Water systems provide a means for transferring energy within an HVAC system. They provide the heating or cooling (sensible and latent) capacity to balance space heating or cooling loads through the mass flow and temperature difference of the water distributed to the conditioned space or process. Testing water-system performance is based on controlling temperature, flow, differential pressure, and liquid level. Typically, this includes open and closed water systems and hot, chilled, and condenser water systems.

Verification of the water system specified performance involves comparing the controller set point to the system control point measured at the sensing device under steady-state operating conditions.

7. SEQUENCE OF OPERATION

7.1 Basic Requirements. Testing the sequence of operation of a control system includes the development of test procedures and the documentation of the operation and performance testing.

The operation of each system component (sensor, controller, and actuator) first is to be verified as operating correctly according to the procedures of Section 5.

A sequence-of-operation test verification plan is to be developed using a step-by-step approach. This approach starts with subsystems and works through the entire system (for example, from temperature sensor/controller for a variable-air-volume [VAV] box up to the control of the entire central AHU VAV system). The test verification plan is to contain the following:

a. List of subsystems and systems to be tested, along with their different sequences of operation (start-up, shutdown, normal, setback, and emergency)

b. Information to be obtained on each test, including measurements to be taken, expected values, instrumentation required, and the procedure to follow

c. Data collection forms

7.2 System Variations. Prior to the initiation of the verification test plan, the following checks are to be completed:

a. The system/component to be tested is fully operational and all ancillary requirements are fully functional (for a central VAV system, for example, the chilled- and hot-water systems are operational and providing water at the required temperature).

b. The control sequences for each component is to be clearly defined with set points, range, etc., then documented and reviewed with all concerned parties prior to testing. The intent of this recommendation is to ensure that the control contractor knows what is expected of the system.

c. The mechanical contractor has certified that the system/component is complete.

d. The basic system verification (commissioning process component) has been completed.

8. PROBLEM SOLVING/CRITICAL TESTING

8.1 General Considerations. The purpose of this section is to describe the general procedures to be followed in the testing of control systems. The testing of control systems is divided into four distinct sequences:

a. Verification of sensors (inputs)

b. Verification of actuators (outputs)

c. Verification of controllers

d. Verification of integrated system operation

8.2 Verification of Sensors. Prior to verifying sensor calibration, it is advised that the following items be confirmed:

a. The sensor meets the application and environment requirements.

b. The sensor is installed in the proper location and orientation.

c. The range of the sensor meets the project specifications or actual operating conditions.

d. The program and/or controller signal matches the sensor configuration. (Example: A chilled-water temperature sensor would not have a range of 0°F to 212°F (0°C to 100°C). However, a 0-10 V signal would be acceptable if it matches the controller.)

Each sensor (temperature, humidity, position, CO₂, etc.), will be evaluated using one or more steps to determine whether the sensor is performing accurately.

For example, for a temperature sensor, the sensor will initially be tested at the midpoint of operation (range), and any corrections for offset will be made. Then, the sensor will be tested at 20% and 80% of the range. The data obtained will then be evaluated to determine if the readings obtained match the performance required.

8.3 Verification of Actuators. Actuator operation verification includes the following:

a. The actuator meets the application and environment requirements

b. The actuator is installed in the proper location and orientation

c. The actuator opens and closes the damper, valve, relay, etc., throughout the required operating range. (Note: Project or device requirements may limit the stroke of the actuator.)

d. The actuator operation meets the project specifications or actual operating conditions. (Example: Normal open and direct acting.)

e. The program and/or controller signal matches the actuator configuration. (Example: When the AHU is disabled for freeze protection, the outdoor air damper closes.)

8.4 Verification of Controllers and/or Program Functions. Controller and/or program function verification is accomplished by systematically manipulating individual inputs or set points and verifying that the responses meet the system or project requirements. (Example: When the room temperature increases above set point, the fan-coil unit chilled-water valve opens.)

8.5 Verification of Integrated System Operation. The final step is to ensure that the individual components of an HVAC
system function together. (Example: Verify that the preheat and cooling coils are not operating at the same time.)

8.6 Advanced Testing Repeatability and Accuracy Loop-Tuning Checkout. Tuning of controllers and/or programs to improve the performance of a control system is not to be undertaken without first controlling the system by overriding various set points in the controller and determining the answer to the following questions:

a. Is the process noisy (rapid oscillations of the control variable)?
b. Is there hysteresis in the actuator response that affects control function?
c. Are there inefficiencies in the mechanical linkage?
d. How easy (or difficult) is it to maintain or change set point?
e. In which operating region is the process most sensitive (highest gain)?
f. Are there other factors that are affecting this part of the system?

Before beginning loop tuning, issues negatively affecting control need to be identified and corrected.

Common problems with poor control-loop performance can be as follows:

a. Time lags that are large compared to the process-reaction rate or system time constant. Time lags can be generated by loop program parameters. For example, a change of value or time period that a loop is updated. Other control systems are part of a larger communication system that may be slowed by excessive traffic. A long dead time frequently creates a tuning challenge that may require a cascaded-loop strategy.
b. Poor measurements of the process variable. This may result from a noise, location, or accuracy issue. For example, using Pitot tubes to measure air velocities below 600 fpm (3.048 m/s) is an accuracy issue.
c. Inadequate device turndown, making it impossible to reduce the output of that device below that required for the control loop. For example, variable-air-volume (VAV) box minimum airflow set points that require the supply fan variable-frequency drive (VFD) to operate below the motors minimum speed.
d. Changes in system gain that occur with changes in the operating point. Typically, these issues are generated by changes in load or capacity. For example, mixed-air damper temperature control can vary with the difference between the outdoor air and return air temperatures.
e. Hysteresis within the control components, which create a time lag due to the inability to react immediately to a change in signal or force. For example, a sticking valve stem or damper or loose mechanical linkage. (Note: See Informative Appendix B for more information on tuning loops.)

9. DOCUMENTATION

The final report is to contain sufficient detail and documentation to show the testing results and identify the specific project, systems, and devices. Each device tested is to be identified and listed in the corresponding testing report.

9.1 Requirements of Reporting. The accurate and understandable documentation of the results of testing is absolutely essential to the completion of a testing project and operation of the facility. The points tested, the design requirements, and the test results obtained are listed to allow the designer to confirm correct operation and for the operator to reference for later maintenance operations.

9.2 Checklists, Spreadsheets, Summaries. The presentation of testing data in an organized form is usually done with spreadsheets. However, other methods are acceptable. (Example: Building and installation inspection tasks can be shown on checklists.)

The overall operational summaries can be conveyed by general descriptions, numbered listings, drawings, pictures, or other illustration methods. To assist with user comprehension, it is advisable that the report be presented in an organized fashion. (Example: VAV terminals listed by system, starting at the closest to the unit.)

9.3 Test Instrumentation

9.3.1 Calibration Verification. Testing of control sensors cannot be done without instruments. The instruments used in the project are to be listed in the project report, along with the required calibration information dates. This informs those reviewing the report of the specific instruments involved in the testing. Additionally, this information provides the building operators a reference to acquire similar instruments.

9.4 Distribution. Deficiencies, preliminary data, and the final report are to be distributed in accordance with contractual requirements. (Note: It is advisable to request permission from the appropriate authority before distribution of any documentation.)

10. REFERENCES


(Note: Refer to ASHRAE Guidelines 13 and 36 for additional reading on more in-depth testing.)
INFORMATIVE APPENDIX A
INSTRUCTIONS FOR TESTING AND FOR COMPLETING TEST FORMS

A1. INSTRUCTIONS FOR TESTING HUMIDITY CONTROL SYSTEMS

Testing of the humidity control system, according to Section 6.2.4, requires a review of how the humidity system components are selected and applied, as well as verification of the humidity sensing devices as described in Section 5.1.2. Also, see the 2007 ASHRAE Handbook—HVAC Applications, Chapter 46, “Design and Application of Controls,” for additional information on the application of humidity control systems. This requires the following:

a. Reviewing the psychrometric process to determine if the entering air conditions and the capacity of the humidifier will provide the desired humidification and if the leaving air conditions and the capacity of the dehumidifier will provide the desired dehumidification.

b. Determining if the accuracy of the humidity sensing device matches the desired accuracy for the humidity control system.

c. Checking the temperature and flow of the medium used in air washers and desiccant systems.

d. Reviewing the type (on-off, step, or modulating) of control and turndown of the humidity system controlled device to determine if the specified system accuracy is achievable.

e. Checking the sequence of controls.

f. Testing the humidity control system under normal operating conditions by comparing system set point to control point. A trend log is recommended to verify results.

g. Testing secondary loops required for limit or cascade control. This requires adjusting the primary loop as required to verify secondary loop operation.

A2. INSTRUCTIONS FOR TESTING WATER SYSTEMS

Testing of water-system control loop, according to Section 6.3.1, requires a review of how the control components are selected and applied, as well as verification of performance of the temperature, flow, pressure, and/or level sensing devices as described in Section 5.2. Also, see the 2007 ASHRAE Handbook—HVAC Applications, Chapter 46, “Design and Application of Controls,” for additional information on the application of water-system control. This requires the following:

a. Checking the input capability of the source device (boiler, chiller, tower, etc.), and pumps for the required water temperature and flow.

b. Checking the entering conditions to the heat exchanger to ensure that leaving conditions can be met.

c. Determining whether the accuracy of the sensing device matches the desired accuracy for the water-system control loop.

d. Reviewing the type of control (on-off, step, or modulating) and turndown of the controlled device (valve, relay, etc.) to determine whether the specified system accuracy is achievable.

e. Checking the control sequence of operation.

f. Testing the water-system control loop under normal operating conditions by comparing loop set point to loop control point. A trend log is recommended to verify results.

A3. INSTRUCTIONS FOR COMPLETING FORM A
(REPORTING ON RELATIVE HUMIDITY DEVICES)

Form A may be used as a testing and commissioning acceptance form. The column headings are as follows:

a. System ID. Identifies the system on which the device is used.

b. Device ID. Identifies device.

c. Type of Device. (H) % relative humidity sensor; (DP) dew-point temperature sensor.

d. Function of Device. (C) control; (M) monitor only; (Hi) high-limit control.

e. Sensor Range. Per vendor description. (Example: 20% to 80%; 0°F to 120°F; -17°C to 48.9°C)

f. Sensor Accuracy. In engineering units. (Example: ±5%; ±2°F; ±1°C)

g. Humidity Device Reading. (% rh) % relative humidity; (°F) degrees Fahrenheit; (°C) degrees Celsius. Readings taken at EMCS monitor at the same time as the test device reading.

h. Test Device Reading. (% rh) % relative humidity; (°F) degrees Fahrenheit; (°C) degrees Celsius.

i. Test Result. Within defined limits as defined by specifications. (Example: Passed [P]—within 2.5 times of humidity device accuracy; marginal [M]—within 2.5 to 4 times humidity device accuracy; failed [F]—exceeds 4 times humidity device accuracy.)

A4. INSTRUCTIONS FOR COMPLETING FORM B
(REPORTING ON WATER-SYSTEM DEVICES)

Form B may be used as a testing or commissioning acceptance form for testing most water-system sensor/devices. The column headings are as follows:

a. System ID. Identifies device is used on.

b. Device ID. Identifies device.

c. Type of Device. Temperature (RTD) resistance temperature detector; (TH) thermistor; (OT) other. Pressure; (EMT) electromechanical transducer; (MG) mechanical gage; (OT) other. Flow rate; (PD) pressure difference; (T) turbine; (PT) Pitot tube; (EM) electromagnetic; (US) ultrasonic; (OT) other. Level: (PD) pressure difference; (FL) electromechanical float; (OT) other.

d. Function of Device. (C) control; (M) monitor only; (S) safety or limit control.

e. Sensor Range. Per vendor description. (Examples: Temperature—0°F to 100°F, 0°C to 50°C; Pressure—0 to 100
### Form A—Testing Humidity and Dew Point Sensing Devices

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td></td>
<td>±</td>
<td>±</td>
</tr>
</tbody>
</table>

### Form B—Testing Water-System Sensing Devices

psi [0 to 500 kPa]; Flow rate—[gpm] gallons per minute, [L/s] litres per second; Level—(ft) feet, (m) metres.

f. Sensor Accuracy. In engineering units. (Examples: Temperature—±2°F, ±1°C; Pressure—±2 psi, ±1 kPa; Flow rate—±10 gpm, ±5 L/s; Level—±1 ft, ±0.5 m.

g. Measuring Device Reading. Temperature: (*F) degrees Fahrenheit, (°C) degrees Celsius. Pressure: (psig) pounds per square inch, (kPa) kilopascals. Flow rate: (gpm) gallons per minute, (L/s) litres per second; Level: (FT) feet, (M) metres. Readings are taken at EMCS monitor at the same time as the test device reading.

h. Test Device Reading. Engineering units are the same as for the measuring device being tested.

i. Test Result. Within defined limits as defined by specifications. (Example: Passed [P]—within 2 times of temperature device accuracy; marginal [M]—within 2 to 4 times of temperature device accuracy; failed [F]—exceeds 4 times temperature device accuracy.)

### A6. INSTRUCTIONS FOR COMPLETING FORM D (REPORTING ON HUMIDITY CONTROL SYSTEMS)

Form D may be used as a testing or commissioning acceptance form. The column readings are explained as follows:

a. System ID. Identifies humidity control system.

b. Type of System. (H) humidification only; (D) dehumidification only; (H/D) both.

c. Type of Control. (O/O) on/off; (S) step; (M) modulating.

d. Set Point. (% rh) % relative humidity; (*F) degrees Fahrenheit; (°C) degrees Celsius.

e. Control Point. Same as set point.

f. Excursion. Control point minus set point. (Example: ±5%; ±2°F; ±1°C.)

g. Specified Accuracy. Example: ±6%; ±4°F; ±2°C.

h. Results. (P) passed; (F) failed. Based on control point excursion not exceeding specified accuracy.

### A7. INSTRUCTIONS FOR COMPLETING FORM E (REPORTING ON WATER-SYSTEM CONTROL LOOPS)

Form E may be used as a testing or commissioning acceptance form. The column readings are explained as follows:

a. System ID. Identifies water-system control loop.

b. Type of System. (T) temperature; (F) flow; (P) pressure; (L) level.
### Form C—Testing Water-System Sensor/Switches

<table>
<thead>
<tr>
<th>System ID</th>
<th>Device ID</th>
<th>Type of Device (T, P, F, L, OT)</th>
<th>Function of Device (L, S, M)</th>
<th>Device Set Point</th>
<th>Device Dead Band</th>
<th>Device Switched Value</th>
<th>Test Result (P, M, F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td>±</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td>±</td>
<td></td>
</tr>
</tbody>
</table>

### Form D—Testing Humidity Control Systems

<table>
<thead>
<tr>
<th>System ID</th>
<th>Type of System (H, D, H/D)</th>
<th>Type of Control (O/O, S, M)</th>
<th>Set Point (% rh, °F, °C)</th>
<th>Control Point (% rh, F, S)</th>
<th>Excursion (±% rh, °F, °C)</th>
<th>Specified Accuracy (±% rh, °F, °C)</th>
<th>Results (P, F)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td>±</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Form E—Testing of Water-System Control List

- **Type of Control.** (O/O) on/off; (S) step; (M) modulating.
- **Set Point.** (°F) degrees Fahrenheit; (°C) degrees Celsius; (gpm) gallons per minute; (L/s) litres per second; (psi) pounds per square inch; (kPa) kilopascals; (ft) feet; (m) metres.
- **Control Point.** Same as set point.
- **Excursion.** Control point minus set point. (Examples: ±3°F; ±20 L/s; ±5 psi; ±1.5 m)
- **Specified Accuracy.** Examples: ±5°F; ±30 L/s; ±8 psi; ±2 m.
- **Results.** (P) passed; (F) failed. Based on control point excursion not exceeding specified accuracy.

---

**References**

INFORMATIVE APPENDIX B
TUNING PI CONTROLLERS

Popular methods of determining proportional-integral (PI) controller tuning parameters include closed-loop and open-loop process identification methods and trial-and-error methods. The closed-loop method increases the gain of the controller in a proportional-only mode until the equipment continuously cycles after a set point change. Proportional and integral terms are then computed from the cycle's period of oscillation and the proportional value that caused cycling.

The open-loop method introduces a step-change input into the open control loop. A graphical technique is used to estimate the process transfer function parameters. Proportional and integral terms are calculated from the estimated process parameters using a series of equations. The trial-and-error method involves adjusting the gain of the proportional-only controller until the desired response to a set point is observed. Conservative tuning dictates that this response should have a small initial overshoot and quickly damp to steady-state conditions. Set point changes should be made in the range where controller saturation, or output limit, is avoided. The integral term is then increased until changes in set point produce the same dynamic response as the controller under proportional control but with the response centered about the set point.

Most manufactures of digital control systems have tuning procedures available either as a built-in or self-tuning process or as a separate package that accepts the tuning parameters and sets or recommends the appropriate gains.
POLICY STATEMENT DEFINING ASHRAE'S CONCERN
FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its Handbook, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.
About ASHRAE
ASHRAE, founded in 1894, is a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability. Through research, Standards writing, publishing, certification and continuing education, ASHRAE shapes tomorrow’s built environment today.

For more information or to become a member of ASHRAE, visit www.ashrae.org.

To stay current with this and other ASHRAE Standards and Guidelines, visit www.ashrae.org/standards.

Visit the ASHRAE Bookstore
ASHRAE offers its Standards and Guidelines in print, as immediately downloadable PDFs, on CD-ROM, and via ASHRAE Digital Collections, which provides online access with automatic updates as well as historical versions of publications. Selected Standards and Guidelines are also offered in redline versions that indicate the changes made between the active Standard or Guideline and its previous edition. For more information, visit the Standards and Guidelines section of the ASHRAE Bookstore at www.ashrae.org/bookstore.

IMPORTANT NOTICES ABOUT THIS GUIDELINE
To ensure that you have all of the approved addenda, errata, and interpretations for this Guideline, visit www.ashrae.org/standards to download them free of charge.

Addenda, errata, and interpretations for ASHRAE Standards and Guidelines are no longer distributed with copies of the Standards and Guidelines. ASHRAE provides these addenda, errata, and interpretations only in electronic form to promote more sustainable use of resources.