

## **SECTION 23 05 93 – TESTING, ADJUSTING, AND BALANCING FOR HVAC**

### **PART 1 - GENERAL**

#### **1.1 RELATED DOCUMENTS**

- A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.

#### **1.2 SUMMARY**

- A. This Section includes TAB to produce design objectives for the following:
  - 1. Air Systems:
    - a. Constant-volume air systems.
    - b. Dual-duct systems.
    - c. Variable-air-volume systems.
    - d. Multizone systems.
    - e. Induction-unit systems.
  - 2. Hydronic Piping Systems:
    - a. Constant-flow systems.
    - b. Variable-flow systems.
    - c. Primary-secondary systems.
  - 3. Steam systems.
  - 4. HVAC equipment quantitative-performance settings.
  - 5. Kitchen hood airflow balancing.
  - 6. Laboratory fume hood airflow balancing.
  - 7. Exhaust hood airflow balancing.
  - 8. Space pressurization testing and adjusting.
  - 9. Vibration measuring.
  - 10. Sound level measuring.
  - 11. Stair-tower pressurization testing and adjusting.
  - 12. Smoke-control systems testing and adjusting.
  - 13. Indoor-air quality measuring.
  - 14. Existing systems TAB.
  - 15. Verifying that automatic control devices are functioning properly.
  - 16. Reporting results of activities and procedures specified in this Section.

#### **1.3 DEFINITIONS**

- A. Adjust: To regulate fluid flow rate and air patterns at the terminal equipment, such as to reduce fan speed or adjust a damper.

- B. Balance: To proportion flows within the distribution system, including submains, branches, and terminals, according to indicated quantities.
- C. Barrier or Boundary: Construction, either vertical or horizontal, such as walls, floors, and ceilings that are designed and constructed to restrict the movement of airflow, smoke, odors, and other pollutants.
- D. Draft: A current of air, when referring to localized effect caused by one or more factors of high air velocity, low ambient temperature, or direction of airflow, whereby more heat is withdrawn from a person's skin than is normally dissipated.
- E. NC: Noise criteria.
- F. Procedure: An approach to and execution of a sequence of work operations to yield repeatable results.
- G. RC: Room criteria.
- H. Report Forms: Test data sheets for recording test data in logical order.
- I. Smoke-Control System: An engineered system that uses fans to produce airflow and pressure differences across barriers to limit smoke movement.
- J. Smoke-Control Zone: A space within a building that is enclosed by smoke barriers and is a part of a zoned smoke-control system.
- K. Stair Pressurization System: A type of smoke-control system that is intended to positively pressurize stair towers with outdoor air by using fans to keep smoke from contaminating the stair towers during an alarm condition.
- L. Static Head: The pressure due to the weight of the fluid above the point of measurement. In a closed system, static head is equal on both sides of the pump.
- M. Suction Head: The height of fluid surface above the centerline of the pump on the suction side.
- N. System Effect: A phenomenon that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system.
- O. System Effect Factors: Allowances used to calculate a reduction of the performance ratings of a fan when installed under conditions different from those presented when the fan was performance tested.
- P. TAB: Testing, adjusting, and balancing.
- Q. Terminal: A point where the controlled medium, such as fluid or energy, enters or leaves the distribution system.
- R. Test: A procedure to determine quantitative performance of systems or equipment.
- S. Testing, Adjusting, and Balancing (TAB) Firm: The entity responsible for performing and reporting TAB procedures.

#### 1.4 SUBMITTALS

- A. Qualification Data: Within **30** days from Contractor's Notice to Proceed, submit **2** copies of evidence that TAB firm and this Project's TAB team members meet the qualifications specified in "Quality Assurance" Article.
- B. Contract Documents Examination Report: Within **30** days from Contractor's Notice to Proceed, submit **2** copies of the Contract Documents review report as specified in Part 3.
- C. Strategies and Procedures Plan: Within **60** days from Contractor's Notice to Proceed, submit **2** copies of TAB strategies and step-by-step procedures as specified in Part 3 "Preparation" Article. Include a complete set of report forms intended for use on this Project.
- D. Certified TAB Reports: Submit two copies of reports prepared, as specified in this Section, on approved forms certified by TAB firm.
- E. Sample Report Forms: Submit two sets of sample TAB report forms.
- F. Warranties specified in this Section.

#### 1.5 QUALITY ASSURANCE

- A. TAB Firm Qualifications: Engage a TAB firm certified by either NEBB or **AABC**.
- B. TAB Conference: Meet with Owner's and Architect's representatives on approval of TAB strategies and procedures plan to develop a mutual understanding of the details. Ensure the participation of TAB team members, equipment manufacturers' authorized service representatives, HVAC controls installers, and other support personnel. Provide seven days' advance notice of scheduled meeting time and location.
  - 1. Agenda Items: Include at least the following:
    - a. Submittal distribution requirements.
    - b. The Contract Documents examination report.
    - c. TAB plan.
    - d. Work schedule and Project-site access requirements.
    - e. Coordination and cooperation of trades and subcontractors.
    - f. Coordination of documentation and communication flow.
- C. Certification of TAB Reports: Certify TAB field data reports. This certification includes the following:
  - 1. Review field data reports to validate accuracy of data and to prepare certified TAB reports.
  - 2. Certify that TAB team complied with approved TAB plan and the procedures specified and referenced in this Specification.
- D. TAB Report Forms: Use standard forms from **AABC's "National Standards for Testing and Balancing Heating, Ventilating, and Air Conditioning Systems."** Or DFW standard forms

- E. Instrumentation Type, Quantity, and Accuracy: As described in NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems, " Section II, " Required Instrumentation for NEBB Certification."
- F. Instrumentation Calibration: Calibrate instruments at least every 12 months or more frequently if required by instrument manufacturer.
  - 1. Keep an updated record of instrument calibration that indicates date of calibration and the name of party performing instrument calibration.

## **1.6 PROJECT CONDITIONS**

- A. Partial Owner Occupancy: Owner may occupy completed areas of building before Substantial Completion. Cooperate with Owner during TAB operations to minimize conflicts with Owner's operations.

## **1.7 COORDINATION**

- A. Coordinate the efforts of factory-authorized service representatives for systems and equipment, HVAC controls installers, and other mechanics to operate HVAC systems and equipment to support and assist TAB activities.
- B. Notice: Provide seven days' advance notice for each test. Include scheduled test dates and times.
- C. Perform TAB after leakage and pressure tests on air and water distribution systems have been satisfactorily completed.

## **1.8 WARRANTY**

- A. National Project Performance Guarantee: Provide a guarantee on AABC's "National Standards for Testing and Balancing Heating, Ventilating, and Air Conditioning Systems" forms stating that AABC will assist in completing requirements of the Contract Documents if TAB firm fails to comply with the Contract Documents. Guarantee includes the following provisions:

## **PART 2 - PRODUCTS (Not Applicable)**

## **PART 3 - EXECUTION**

### **3.1 EXAMINATION**

- A. Examine the Contract Documents to become familiar with Project requirements and to discover conditions in systems' designs that may preclude proper TAB of systems and equipment.
  - 1. Contract Documents are defined in the General and Supplementary Conditions of Contract.

2. Verify that balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are required by the Contract Documents. Verify that quantities and locations of these balancing devices are accessible and appropriate for effective balancing and for efficient system and equipment operation.
- B. Examine approved submittal data of HVAC systems and equipment.
- C. Examine Project Record Documents described in Division 01 Section "Project Record Documents."
- D. Examine design data, including HVAC system descriptions, statements of design assumptions for environmental conditions and systems' output, and statements of philosophies and assumptions about HVAC system and equipment controls.
- E. Examine equipment performance data including fan and pump curves. Relate performance data to Project conditions and requirements, including system effects that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system. Calculate system effect factors to reduce performance ratings of HVAC equipment when installed under conditions different from those presented when the equipment was performance tested at the factory. To calculate system effects for air systems, use tables and charts found in AMCA 201, "Fans and Systems," Sections 7 through 10; or in SMACNA's "HVAC Systems--Duct Design," Sections 5 and 6. Compare this data with the design data and installed conditions.
- F. Examine system and equipment installations to verify that they are complete and that testing, cleaning, adjusting, and commissioning specified in individual Sections have been performed.
- G. Examine system and equipment test reports.
- H. Examine HVAC system and equipment installations to verify that indicated balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are properly installed, and that their locations are accessible and appropriate for effective balancing and for efficient system and equipment operation.
- I. Examine systems for functional deficiencies that cannot be corrected by adjusting and balancing.
- J. Examine HVAC equipment to ensure that clean filters have been installed, bearings are greased, belts are aligned and tight, and equipment with functioning controls is ready for operation.
- K. Examine terminal units, such as variable-air-volume boxes, to verify that they are accessible and their controls are connected and functioning.
- L. Examine plenum ceilings used for supply air to verify that they are airtight. Verify that pipe penetrations and other holes are sealed.
- M. Examine strainers for clean screens and proper perforations.
- N. Examine three-way valves for proper installation for their intended function of diverting or mixing fluid flows.

- O. Examine heat-transfer coils for correct piping connections and for clean and straight fins.
- P. Examine system pumps to ensure absence of entrained air in the suction piping.
- Q. Examine equipment for installation and for properly operating safety interlocks and controls.
- R. Examine automatic temperature system components to verify the following:
  - 1. Dampers, valves, and other controlled devices are operated by the intended controller.
  - 2. Dampers and valves are in the position indicated by the controller.
  - 3. Integrity of valves and dampers for free and full operation and for tightness of fully closed and fully open positions. This includes dampers in multizone units, mixing boxes, and variable-air-volume terminals.
  - 4. Automatic modulating and shutoff valves, including two-way valves and three-way mixing and diverting valves, are properly connected.
  - 5. Thermostats and humidistats are located to avoid adverse effects of sunlight, drafts, and cold walls.
  - 6. Sensors are located to sense only the intended conditions.
  - 7. Sequence of operation for control modes is according to the Contract Documents.
  - 8. Controller set points are set at indicated values.
  - 9. Interlocked systems are operating.
  - 10. Changeover from heating to cooling mode occurs according to indicated values.
- S. Report deficiencies discovered before and during performance of TAB procedures. Observe and record system reactions to changes in conditions. Record default set points if different from indicated values.

### 3.2 PREPARATION

- A. Prepare a TAB plan that includes strategies and step-by-step procedures.
- B. Complete system readiness checks and prepare system readiness reports. Verify the following:
  - 1. Permanent electrical power wiring is complete.
  - 2. Hydronic systems are filled, clean, and free of air.
  - 3. Automatic temperature-control systems are operational.
  - 4. Equipment and duct access doors are securely closed.
  - 5. Balance, smoke, and fire dampers are open.
  - 6. Isolating and balancing valves are open and control valves are operational.
  - 7. Ceilings are installed in critical areas where air-pattern adjustments are required and access to balancing devices is provided.
  - 8. Windows and doors can be closed so indicated conditions for system operations can be met.

### 3.3 GENERAL PROCEDURES FOR TESTING AND BALANCING

- A. Perform testing and balancing procedures on each system according to the procedures contained in **AABC's "National Standards for Testing and Balancing Heating, Ventilating, and Air Conditioning Systems"** and this Section.

- B. Cut insulation, ducts, pipes, and equipment cabinets for installation of test probes to the minimum extent necessary to allow adequate performance of procedures. After testing and balancing, close probe holes and patch insulation with new materials identical to those removed. Restore vapor barrier and finish according to insulation Specifications for this Project.
- C. Mark equipment and balancing device settings with paint or other suitable, permanent identification material, including damper-control positions, valve position indicators, fan-speed-control levers, and similar controls and devices, to show final settings.
- D. Take and report testing and balancing measurements in **inch-pound (IP)** units.

### **3.4 GENERAL PROCEDURES FOR BALANCING AIR SYSEMS**

- A. Prepare test reports for both fans and outlets. Obtain manufacturer's outlet factors and recommended testing procedures. Crosscheck the summation of required outlet volumes with required fan volumes.
- B. Prepare schematic diagrams of systems' "as-built" duct layouts.
- C. For variable-air-volume systems, develop a plan to simulate diversity.
- D. Determine the best locations in main and branch ducts for accurate duct airflow measurements.
- E. Check airflow patterns from the outside-air louvers and dampers and the return- and exhaust-air dampers, through the supply-fan discharge and mixing dampers.
- F. Locate start-stop and disconnect switches, electrical interlocks, and motor starters.
- G. Verify that motor starters are equipped with properly sized thermal protection.
- H. Check dampers for proper position to achieve desired airflow path.
- I. Check for airflow blockages.
- J. Check condensate drains for proper connections and functioning.
- K. Check for proper sealing of air-handling unit components.
- L. Check for proper sealing of air duct system.

### **3.5 PROCEDURES FOR CONSTANT-VOLUME AIR SYSTEMS**

- A. Adjust fans to deliver total indicated airflows within the maximum allowable fan speed listed by fan manufacturer.
  - 1. Measure fan static pressures to determine actual static pressure as follows:
    - a. Measure outlet static pressure as far downstream from the fan as practicable and upstream from restrictions in ducts such as elbows and transitions.
    - b. Measure static pressure directly at the fan outlet or through the flexible connection.

- c. Measure inlet static pressure of single-inlet fans in the inlet duct as near the fan as possible, upstream from flexible connection and downstream from duct restrictions.
    - d. Measure inlet static pressure of double-inlet fans through the wall of the plenum that houses the fan.
  2. Measure static pressure across each component that makes up an air-handling unit, rooftop unit, and other air-handling and -treating equipment.
    - a. Simulate dirty filter operation and record the point at which maintenance personnel must change filters.
  3. Measure static pressures entering and leaving other devices such as sound traps, heat recovery equipment, and air washers, under final balanced conditions.
  4. Compare design data with installed conditions to determine variations in design static pressures versus actual static pressures. Compare actual system effect factors with calculated system effect factors to identify where variations occur. Recommend corrective action to align design and actual conditions.
  5. Obtain approval from Architect for adjustment of fan speed higher or lower than indicated speed. Make required adjustments to pulley sizes, motor sizes, and electrical connections to accommodate fan-speed changes.
  6. Do not make fan-speed adjustments that result in motor overload. Consult equipment manufacturers about fan-speed safety factors. Modulate dampers and measure fan-motor amperage to ensure that no overload will occur. Measure amperage in full cooling, full heating, economizer, and any other operating modes to determine the maximum required brake horsepower.
- B. Adjust volume dampers for main duct, submain ducts, and major branch ducts to indicated airflows within specified tolerances.
  1. Measure static pressure at a point downstream from the balancing damper and adjust volume dampers until the proper static pressure is achieved.
    - a. Where sufficient space in submain and branch ducts is unavailable for Pitot-tube traverse measurements, measure airflow at terminal outlets and inlets and calculate the total airflow for that zone.
  2. Remeasure each submain and branch duct after all have been adjusted. Continue to adjust submain and branch ducts to indicated airflows within specified tolerances.
- C. Measure terminal outlets and inlets without making adjustments.
  1. Measure terminal outlets using a direct-reading hood or outlet manufacturer's written instructions and calculating factors.
- D. Adjust terminal outlets and inlets for each space to indicated airflows within specified tolerances of indicated values. Make adjustments using volume dampers rather than extractors and the dampers at air terminals.
  1. Adjust each outlet in same room or space to within specified tolerances of indicated quantities without generating noise levels above the limitations prescribed by the Contract Documents.
  2. Adjust patterns of adjustable outlets for proper distribution without drafts.



### 3.6 PROCEDURES FOR VARIABLE-AIR-VOLUME SYSTEMS

- A. Compensating for Diversity: When the total airflow of all terminal units is more than the indicated airflow of the fan, place a selected number of terminal units at a maximum set-point airflow condition until the total airflow of the terminal units equals the indicated airflow of the fan. Select the reduced airflow terminal units so they are distributed evenly among the branch ducts.
- B. Pressure-Independent, Variable-Air-Volume Systems: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
  - 1. Set outside-air dampers at minimum, and return- and exhaust-air dampers at a position that simulates full-cooling load.
  - 2. Select the terminal unit that is most critical to the supply-fan airflow and static pressure. Measure static pressure. Adjust system static pressure so the entering static pressure for the critical terminal unit is not less than the sum of terminal-unit manufacturer's recommended minimum inlet static pressure plus the static pressure needed to overcome terminal-unit discharge system losses.
  - 3. Measure total system airflow. Adjust to within indicated airflow.
  - 4. Set terminal units at maximum airflow and adjust controller or regulator to deliver the designed maximum airflow. Use terminal-unit manufacturer's written instructions to make this adjustment. When total airflow is correct, balance the air outlets downstream from terminal units as described for constant-volume air systems.
  - 5. Set terminal units at minimum airflow and adjust controller or regulator to deliver the designed minimum airflow. Check air outlets for a proportional reduction in airflow as described for constant-volume air systems.
    - a. If air outlets are out of balance at minimum airflow, report the condition but leave outlets balanced for maximum airflow.
  - 6. Remeasure the return airflow to the fan while operating at maximum return airflow and minimum outside airflow. Adjust the fan and balance the return-air ducts and inlets as described for constant-volume air systems.
  - 7. Measure static pressure at the most critical terminal unit and adjust the static-pressure controller at the main supply-air sensing station to ensure that adequate static pressure is maintained at the most critical unit.
  - 8. Record the final fan performance data.
- C. Pressure-Dependent, Variable-Air-Volume Systems without Diversity: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
  - 1. Balance systems similar to constant-volume air systems.
  - 2. Set terminal units and supply fan at full-airflow condition.
  - 3. Adjust inlet dampers of each terminal unit to indicated airflow and verify operation of the static-pressure controller. When total airflow is correct, balance the air outlets downstream from terminal units as described for constant-volume air systems.
  - 4. Readjust fan airflow for final maximum readings.
  - 5. Measure operating static pressure at the sensor that controls the supply fan, if one is installed, and verify operation of the static-pressure controller.
  - 6. Set supply fan at minimum airflow if minimum airflow is indicated. Measure static pressure to verify that it is being maintained by the controller.

7. Set terminal units at minimum airflow and adjust controller or regulator to deliver the designed minimum airflow. Check air outlets for a proportional reduction in airflow as described for constant-volume air systems.
    - a. If air outlets are out of balance at minimum airflow, report the condition but leave the outlets balanced for maximum airflow.
  8. Measure the return airflow to the fan while operating at maximum return airflow and minimum outside airflow. Adjust the fan and balance the return-air ducts and inlets as described for constant-volume air systems.
- D. Pressure-Dependent, Variable-Air-Volume Systems with Diversity: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
1. Set system at maximum indicated airflow by setting the required number of terminal units at minimum airflow. Select the reduced airflow terminal units so they are distributed evenly among the branch ducts.
  2. Adjust supply fan to maximum indicated airflow with the variable-airflow controller set at maximum airflow.
  3. Set terminal units at full-airflow condition.
  4. Adjust terminal units starting at the supply-fan end of the system and continuing progressively to the end of the system. Adjust inlet dampers of each terminal unit to indicated airflow. When total airflow is correct, balance the air outlets downstream from terminal units as described for constant-volume air systems.
  5. Adjust terminal units for minimum airflow.
  6. Measure static pressure at the sensor.
  7. Measure the return airflow to the fan while operating at maximum return airflow and minimum outside airflow. Adjust the fan and balance the return-air ducts and inlets as described for constant-volume air systems.

### **3.7 PROCEDURES FOR MULTIZONE SYSTEMS**

- A. Set unit at full flow through the cooling coil if coil has that capacity.
- B. Adjust each zone damper to indicated airflow.

### **3.8 GENERAL PROCEDURES FOR HYDRONIC SYSTEMS**

- A. Prepare test reports with pertinent design data and number in sequence starting at pump to end of system. Check the sum of branch-circuit flows against approved pump flow rate. Correct variations that exceed plus or minus 5 percent.
- B. Prepare schematic diagrams of systems' "as-built" piping layouts.
- C. Prepare hydronic systems for testing and balancing according to the following, in addition to the general preparation procedures specified above:
  1. Open all manual valves for maximum flow.
  2. Check expansion tank liquid level.
  3. Check makeup-water-station pressure gage for adequate pressure for highest vent.

4. Check flow-control valves for specified sequence of operation and set at indicated flow.
5. Set differential-pressure control valves at the specified differential pressure. Do not set at fully closed position when pump is positive-displacement type unless several terminal valves are kept open.
6. Set system controls so automatic valves are wide open to heat exchangers.
7. Check pump-motor load. If motor is overloaded, throttle main flow-balancing device so motor nameplate rating is not exceeded.
8. Check air vents for a forceful liquid flow exiting from vents when manually operated.

### 3.9 PROCEDURES FOR HYDRONIC SYSTEMS

- A. Measure water flow at pumps. Use the following procedures, except for positive-displacement pumps:
  1. Verify impeller size by operating the pump with the discharge valve closed. Read pressure differential across the pump. Convert pressure to head and correct for differences in gage heights. Note the point on manufacturer's pump curve at zero flow and verify that the pump has the intended impeller size.
  2. Check system resistance. With all valves open, read pressure differential across the pump and mark pump manufacturer's head-capacity curve. Adjust pump discharge valve until indicated water flow is achieved.
  3. Verify pump-motor brake horsepower. Calculate the intended brake horsepower for the system based on pump manufacturer's performance data. Compare calculated brake horsepower with nameplate data on the pump motor. Report conditions where actual amperage exceeds motor nameplate amperage.
  4. Report flow rates that are not within plus or minus 5 percent of design.
- B. Set calibrated balancing valves, if installed, at calculated presettings.
- C. Measure flow at all stations and adjust, where necessary, to obtain first balance.
  1. System components that have Cv rating or an accurately cataloged flow-pressure-drop relationship may be used as a flow-indicating device.
- D. Measure flow at main balancing station and set main balancing device to achieve flow that is 5 percent greater than indicated flow.
- E. Adjust balancing stations to within specified tolerances of indicated flow rate as follows:
  1. Determine the balancing station with the highest percentage over indicated flow.
  2. Adjust each station in turn, beginning with the station with the highest percentage over indicated flow and proceeding to the station with the lowest percentage over indicated flow.
  3. Record settings and mark balancing devices.
- F. Measure pump flow rate and make final measurements of pump amperage, voltage, rpm, pump heads, and systems' pressures and temperatures including outdoor-air temperature.
- G. Measure the differential-pressure control valve settings existing at the conclusions of balancing.

### **3.10 PROCEDURES FOR VARIABLE-FLOW HYDRONIC SYSTEMS**

- A. Balance systems with automatic two- and three-way control valves by setting systems at maximum flow through heat-exchange terminals and proceed as specified above for hydronic systems.

### **3.11 PROCEDURES FOR PRIMARY-SECONDARY-FLOW HYDRONIC SYSTEMS**

- A. Balance the primary system crossover flow first, then balance the secondary system.

### **3.12 PROCEDURES FOR HEAT EXCHANGERS**

- A. Measure water flow through all circuits.
- B. Adjust water flow to within specified tolerances.
- C. Measure inlet and outlet water temperatures.
- D. Measure inlet steam pressure.
- E. Check the setting and operation of safety and relief valves. Record settings.

### **3.13 PROCEDURES FOR MOTORS**

- A. Motors, 1/2 HP and Larger: Test at final balanced conditions and record the following data:
  - 1. Manufacturer, model, and serial numbers.
  - 2. Motor horsepower rating.
  - 3. Motor rpm.
  - 4. Efficiency rating.
  - 5. Nameplate and measured voltage, each phase.
  - 6. Nameplate and measured amperage, each phase.
  - 7. Starter thermal-protection-element rating.
- B. Motors Driven by Variable-Frequency Controllers: Test for proper operation at speeds varying from minimum to maximum. Test the manual bypass for the controller to prove proper operation. Record observations, including controller manufacturer, model and serial numbers, and nameplate data.

### **3.14 PROCEDURES FOR CONDENSING UNITS**

- A. Verify proper rotation of fans.
- B. Measure entering- and leaving-air temperatures.
- C. Record compressor data.

### **3.15 PROCEDURES FOR HEAT-TRANSFER COILS**

- A. Water Coils: Measure the following data for each coil:
  - 1. Entering- and leaving-water temperature.
  - 2. Water flow rate.
  - 3. Water pressure drop.
  - 4. Dry-bulb temperature of entering and leaving air.
  - 5. Wet-bulb temperature of entering and leaving air for cooling coils.
  - 6. Airflow.
  - 7. Air pressure drop.
- B. Electric-Heating Coils: Measure the following data for each coil:
  - 1. Nameplate data.
  - 2. Airflow.
  - 3. Entering- and leaving-air temperature at full load.
  - 4. Voltage and amperage input of each phase at full load and at each incremental stage.
  - 5. Calculated kilowatt at full load.
  - 6. Fuse or circuit-breaker rating for overload protection.
- C. Steam Coils: Measure the following data for each coil:
  - 1. Dry-bulb temperature of entering and leaving air.
  - 2. Airflow.
  - 3. Air pressure drop.
  - 4. Inlet steam pressure.
- D. Refrigerant Coils: Measure the following data for each coil:
  - 1. Dry-bulb temperature of entering and leaving air.
  - 2. Wet-bulb temperature of entering and leaving air.
  - 3. Airflow.
  - 4. Air pressure drop.
  - 5. Refrigerant suction pressure and temperature.

### **3.16 PROCEDURES FOR TEMPERATURE MEASUREMENTS**

- A. During TAB, report the need for adjustment in temperature regulation within the automatic temperature-control system.
- B. Measure indoor wet- and dry-bulb temperatures every other hour for a period of two successive eight-hour days, in each separately controlled zone, to prove correctness of final temperature settings. Measure when the building or zone is occupied.
- C. Measure outside-air, wet- and dry-bulb temperatures.

### **3.17 PROCEDURES FOR EXHAUST HOODS**

- A. Measure, adjust, and record the airflow of each exhaust hood. Measure airflow by duct Pitot-tube traverse. If a duct Pitot-tube traverse is not possible, explain why, in the report, and explain the test method used.
- B. After balancing is complete, do the following:
  - 1. Measure and record the static pressure at the hood exhaust-duct connection.
  - 2. Check the hood for capture and containment of smoke using a smoke emitting device. Observe the smoke pattern. Make adjustments to achieve optimum results.

### **3.18 PROCEDURES FOR SPACE PRESSURIZATION MEASUREMENTS AND ADJUSTMENTS**

- A. Before testing for space pressurization, observe the space to verify the integrity of the space boundaries. Verify that windows and doors are closed and applicable safing, gaskets, and sealants are installed. Report deficiencies and postpone testing until after the reported deficiencies are corrected.
- B. Measure, adjust, and record the pressurization of each room, each zone, and each building by adjusting the supply, return, and exhaust airflows to achieve the indicated conditions.
- C. Measure space pressure differential where pressure is used as the design criteria, and measure airflow differential where differential airflow is used as the design criteria for space pressurization.
  - 1. For pressure measurements, measure and record the pressure difference between the intended spaces at the door with all doors in the space closed. Record the high-pressure side, low-pressure side, and pressure difference between each adjacent space.
  - 2. For applications with cascading levels of space pressurization, begin in the most critical space and work to the least critical space.
  - 3. Test room pressurization first, then zones, and finish with building pressurization.
- D. To achieve indicated pressurization, set the supply airflow to the indicated conditions and adjust the exhaust and return airflow to achieve the indicated pressure or airflow difference.
- E. For spaces with pressurization being monitored and controlled automatically, observe and adjust the controls to achieve the desired set point.
  - 1. Compare the values of the measurements taken to the measured values of the control system instruments and report findings.
  - 2. Check the repeatability of the controls by successive tests designed to temporarily alter the ability to achieve space pressurization. Test overpressurization and underpressurization, and observe and report on the system's ability to revert to the set point.
  - 3. For spaces served by variable-air-volume supply and exhaust systems, measure space pressurization at indicated airflow and minimum airflow conditions.
- F. In spaces that employ multiple modes of operation, such as normal mode and emergency mode or occupied mode and unoccupied mode, measure, adjust, and record data for each operating mode.

- G. Record indicated conditions and corresponding initial and final measurements. Report deficiencies.

### **3.19 PROCEDURES FOR VIBRATION MEASUREMENTS**

- A. Use a vibration meter meeting the following criteria:
  - 1. Solid-state circuitry with a piezoelectric accelerometer.
  - 2. Velocity range of 0.1 to 10 inches per second (2.5 to 254 mm/s).
  - 3. Displacement range of 1 to 100 mils (0.0254 to 2.54 mm).
  - 4. Frequency range of at least 0 to 1000 Hz.
  - 5. Capable of filtering unwanted frequencies.
- B. Calibrate the vibration meter before each day of testing.
  - 1. Use a calibrator provided with the vibration meter.
  - 2. Follow vibration meter and calibrator manufacturer's calibration procedures.
- C. Perform vibration measurements when other building and outdoor vibration sources are at a minimum level and will not influence measurements of equipment being tested.
  - 1. Turn off equipment in the building that might interfere with testing.
  - 2. Clear the space of people.
- D. Perform vibration measurements after air and water balancing and equipment testing is complete.
- E. Clean equipment surfaces in contact with the vibration transducer.
- F. Position the vibration transducer according to manufacturer's written instructions and to avoid interference with the operation of the equipment being tested.
- G. Measure and record vibration on rotating equipment over 3 hp (2.2 kW).
- H. Measure and record equipment vibration, bearing vibration, equipment base vibration, and building structure vibration. Record velocity and displacement readings in the horizontal, vertical, and axial planes.
  - 1. Pumps:
    - a. Pump Bearing: Drive end and opposite end.
    - b. Motor Bearing: Drive end and opposite end.
    - c. Pump Base: Top and side.
    - d. Building: Floor.
    - e. Piping: To and from the pump after flexible connections.
  - 2. Fans and HVAC Equipment with Fans:
    - a. Fan Bearing: Drive end and opposite end.
    - b. Motor Bearing: Drive end and opposite end.
    - c. Equipment Casing: Top and side.

- d. Equipment Base: Top and side.
  - e. Building: Floor.
  - f. Ductwork: To and from equipment after flexible connections.
  - g. Piping: To and from equipment after flexible connections.
- 3. Chillers and HVAC Equipment with Compressors:
  - a. Compressor Bearing: Drive end and opposite end.
  - b. Motor Bearing: Drive end and opposite end.
  - c. Equipment Casing: Top and side.
  - d. Equipment Base: Top and side.
  - e. Building: Floor.
  - f. Piping: To and from equipment after flexible connections.
- I. For equipment with vibration isolation, take floor measurements with the vibration isolation blocked solid to the floor and with the vibration isolation floating. Calculate and report the differences.
- J. Inspect, measure, and record vibration isolation.
  - 1. Verify that vibration isolation is installed in the required locations.
  - 2. Verify that installation is level and plumb.
  - 3. Verify that isolators are properly anchored.
  - 4. For spring isolators, measure the compressed spring height, the spring OD, and the travel-to-solid distance.
  - 5. Measure the operating clearance between each inertia base and the floor or concrete base below. Verify that there is unobstructed clearance between the bottom of the inertia base and the floor.

### **3.20 PROCEDURES FOR SOUND-LEVEL MEASUREMENTS**

- A. Perform sound-pressure-level measurements with an octave-band analyzer complying with ANSI S1.4 for Type 1 sound-level meters and ANSI S1.11 for octave-band filters. Comply with requirements in ANSI S1.13, unless otherwise indicated.
- B. Calibrate sound meters before each day of testing. Use a calibrator provided with the sound meter complying with ANSI S1.40 and that has NIST certification.
- C. Use a microphone that is suitable for the type of sound levels measured. For areas where air velocities exceed 100 fpm (0.51 m/s), use a windscreen on the microphone.
- D. Perform sound-level testing after air and water balancing and equipment testing are complete.
- E. Close windows and doors to the space.
- F. Perform measurements when the space is not occupied and when the occupant noise level from other spaces in the building and outside are at a minimum.
- G. Clear the space of temporary sound sources so unrelated disturbances will not be measured. Position testing personnel during measurements to achieve a direct line-of-sight between the sound source and the sound-level meter.



- H. Take sound measurements at a height approximately 48 inches (1200 mm) above the floor and at least 36 inches (900 mm) from a wall, column, and other large surface capable of altering the measurements.
- I. Take sound measurements in dBA and in each of the 8 unweighted octave bands in the frequency range of 63 to 8000 Hz.
- J. Take sound measurements with the HVAC systems off to establish the background sound levels and take sound measurements with the HVAC systems operating.
  - 1. Calculate the difference between measurements. Apply a correction factor depending on the difference and adjust measurements.
- K. Perform sound testing at 2 locations on Project for each of the following space types. For each space type tested, select a measurement location that has the greatest sound level. If testing multiple locations for each space type, select at least one location that is near and at least one location that is remote from the predominant sound source.
  - 1. Private office.
  - 2. Open office area.
  - 3. Conference room.
  - 4. Auditorium/large meeting room/lecture hall.
  - 5. Classroom/training room.
  - 6. Patient room/exam room.
  - 7. Sound or vibration sensitive laboratory.
  - 8. Hotel room/apartment.
  - 9. Each space with a noise criterion of RC or NC 25 or lower.
  - 10. Each space with an indicated noise criterion of RC or NC 35 and lower that is adjacent to a mechanical equipment room or roof mounted equipment.
  - 11. Inside each mechanical equipment room.
  - 12. Spaces identified by DFWIA

### **3.21 PROCEDURES FOR INDOOR-AIR QUALITY MEASUREMENTS**

- A. After air balancing is complete and with HVAC systems operating at indicated conditions, perform indoor-air quality testing.
- B. Observe and record the following conditions for each HVAC system:
  - 1. The distance between the outside-air intake and the closest exhaust fan discharge, cooling tower, flue termination, or vent termination.
  - 2. Specified filters are installed. Check for leakage around filters.
  - 3. Cooling coil drain pans have a positive slope to drain.
  - 4. Cooling coil condensate drain trap maintains an air seal.
  - 5. Evidence of water damage.
  - 6. Insulation in contact with the supply, return, and outside air is dry and clean.
- C. Measure and record indoor conditions served by each HVAC system. Make measurements at multiple locations served by the system if required to satisfy the following:
  - 1. Most remote area.

2. One location per floor.
  3. One location for every 5000 sq. ft. (500 sq. m).
- D. Measure and record the following indoor conditions for each location two times at two-hour intervals, and in accordance with ASHRAE 113:
1. Temperature.
  2. Relative humidity.
  3. Air velocity.
  4. Concentration of carbon dioxide (ppm).
  5. Concentration of carbon monoxide (ppm).
  6. Nitrogen oxides (ppm).
  7. Formaldehyde (ppm).

### **3.22 PROCEDURES FOR TESTING, ADJUSTING, AND BALANCING EXISTING SYSTEMS**

- A. Perform a preconstruction inspection of existing equipment that is to remain and be reused.
1. Measure and record the operating speed, airflow, and static pressure of each fan.
  2. Measure motor voltage and amperage. Compare the values to motor nameplate information.
  3. Check the refrigerant charge.
  4. Check the condition of filters.
  5. Check the condition of coils.
  6. Check the operation of the drain pan and condensate drain trap.
  7. Check bearings and other lubricated parts for proper lubrication.
  8. Report on the operating condition of the equipment and the results of the measurements taken. Report deficiencies.
- B. Before performing testing and balancing of existing systems, inspect existing equipment that is to remain and be reused to verify that existing equipment has been cleaned and refurbished.
1. New filters are installed.
  2. Coils are clean and fins combed.
  3. Drain pans are clean.
  4. Fans are clean.
  5. Bearings and other parts are properly lubricated.
  6. Deficiencies noted in the preconstruction report are corrected.
- C. Perform testing and balancing of existing systems to the extent that existing systems are affected by the renovation work.
1. Compare the indicated airflow of the renovated work to the measured fan airflows and determine the new fan, speed, filter, and coil face velocity.
  2. Verify that the indicated airflows of the renovated work result in filter and coil face velocities and fan speeds that are within the acceptable limits defined by equipment manufacturer.
  3. If calculations increase or decrease the airflow and water flow rates by more than 5 percent, make equipment adjustments to achieve the calculated airflow and water flow rates. If 5 percent or less, equipment adjustments are not required.
  4. Air balance each air outlet.

### **3.23 TEMPERATURE-CONTROL VERIFICATION**

- A. Verify that controllers are calibrated and commissioned.
- B. Verify that sensors including thermostats, static pressure sensors, temperature sensors, etc. are properly calibrated per manufacturer's instructions.
- C. Check transmitter and controller locations and note conditions that would adversely affect control functions.
- D. Record controller settings and note variances between set points and actual measurements.
- E. Check the operation of limiting controllers (i.e., high- and low-temperature controllers).
- F. Check free travel and proper operation of control devices such as damper and valve operators.
- G. Check the sequence of operation of control devices. Note air pressures and device positions and correlate with airflow and water flow measurements. Note the speed of response to input changes.
- H. Check the interaction of electrically operated switch transducers.
- I. Check the interaction of interlock and lockout systems.
- J. Check main control supply-air pressure and observe compressor and dryer operations.
- K. Record voltages of power supply and controller output. Determine whether the system operates on a grounded or nongrounded power supply.
- L. Note operation of electric actuators using spring return for proper fail-safe operations.

### **3.24 TOLERANCES**

- A. Set HVAC system airflow and water flow rates within the following tolerances:
  - 1. Supply, Return, and Exhaust Fans and Equipment with Fans: Minus 5 to plus 10 percent.
  - 2. Air Outlets and Inlets: 0 to minus 10 percent.
  - 3. Heating-Water Flow Rate: 0 to minus 10 percent.
  - 4. Cooling-Water Flow Rate: 0 to minus 5 percent.

### **3.25 REPORTING**

- A. Initial Construction-Phase Report: Based on examination of the Contract Documents as specified in "Examination" Article, prepare a report on the adequacy of design for systems' balancing devices. Recommend changes and additions to systems' balancing devices to facilitate proper performance measuring and balancing. Recommend changes and additions to HVAC systems and general construction to allow access for performance measuring and balancing devices.

- B. Status Reports: As Work progresses, prepare reports to describe completed procedures, procedures in progress, and scheduled procedures. Include a list of deficiencies and problems found in systems being tested and balanced. Prepare a separate report for each system and each building floor for systems serving multiple floors.

### **3.26 FINAL REPORT**

- A. General: Report shall be provided in both digital and physical format. The digital copy shall be a PDF. The physical copy shall be typewritten, or computer printout in letter-quality font, on standard bond paper, in three-ring binder, tabulated and divided into sections by tested and balanced systems.
- B. Include sensor and controller calibration information.
- C. Include a certification sheet in front of binder signed and sealed by the certified testing and balancing engineer.
  - 1. Include a list of instruments used for procedures, along with proof of calibration.
- D. Final Report Contents: In addition to certified field report data, include the following:
  - 1. Pump curves.
  - 2. Fan curves.
  - 3. Manufacturers' test data.
  - 4. Field test reports prepared by system and equipment installers.
  - 5. Other information relative to equipment performance, but do not include Shop Drawings and Product Data.
- E. General Report Data: In addition to form titles and entries, include the following data in the final report, as applicable:
  - 1. Title page.
  - 2. Name and address of TAB firm.
  - 3. Project name.
  - 4. Project location.
  - 5. Architect's name and address.
  - 6. Engineer's name and address.
  - 7. Contractor's name and address.
  - 8. Report date.
  - 9. Signature of TAB firm who certifies the report.
  - 10. Table of Contents with the total number of pages defined for each section of the report. Number each page in the report.
  - 11. Summary of contents including the following:
    - a. Indicated versus final performance.
    - b. Notable characteristics of systems.
    - c. Description of system operation sequence if it varies from the Contract Documents.
  - 12. Nomenclature sheets for each item of equipment.
  - 13. Data for terminal units, including manufacturer, type size, and fittings.

14. Notes to explain why certain final data in the body of reports varies from indicated values.
  15. Test conditions for fans and pump performance forms including the following:
    - a. Settings for outside-, return-, and exhaust-air dampers.
    - b. Conditions of filters.
    - c. Cooling coil, wet- and dry-bulb conditions.
    - d. Face and bypass damper settings at coils.
    - e. Fan drive settings including settings and percentage of maximum pitch diameter.
    - f. Inlet vane settings for variable-air-volume systems.
    - g. Settings for supply-air, static-pressure controller.
    - h. Other system operating conditions that affect performance.
- F. System Diagrams: Include schematic layouts of air and hydronic distribution systems. Present each system with single-line diagram and include the following:
1. Quantities of outside, supply, return, and exhaust airflows.
  2. Water and steam flow rates.
  3. Duct, outlet, and inlet sizes.
  4. Pipe and valve sizes and locations.
  5. Terminal units.
  6. Balancing stations.
  7. Position of balancing devices.
- G. Air-Handling Unit Test Reports: For air-handling units with coils, include the following:
1. Unit Data: Include the following:
    - a. Unit identification.
    - b. Location.
    - c. Make and type.
    - d. Model number and unit size.
    - e. Manufacturer's serial number.
    - f. Unit arrangement and class.
    - g. Discharge arrangement.
    - h. Sheave make, size in inches (mm), and bore.
    - i. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
    - j. Number of belts, make, and size.
    - k. Number of filters, type, and size.
  2. Motor Data:
    - a. Make and frame type and size.
    - b. Horsepower and rpm.
    - c. Volts, phase, and hertz.
    - d. Full-load amperage and service factor.
    - e. Sheave make, size in inches (mm), and bore.
    - f. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
  3. Test Data (Indicated and Actual Values):
    - a. Total airflow rate in cfm (L/s).
    - b. Total system static pressure in inches wg (Pa).

- c. Fan rpm.
- d. Discharge static pressure in inches wg (Pa).
- e. Filter static-pressure differential in inches wg (Pa).
- f. Preheat coil static-pressure differential in inches wg (Pa).
- g. Cooling coil static-pressure differential in inches wg (Pa).
- h. Heating coil static-pressure differential in inches wg (Pa).
- i. Outside airflow in cfm (L/s).
- j. Return airflow in cfm (L/s).
- k. Outside-air damper position.
- l. Return-air damper position.
- m. Vortex damper position.

H. Apparatus-Coil Test Reports:

1. Coil Data:

- a. System identification.
- b. Location.
- c. Coil type.
- d. Number of rows.
- e. Fin spacing in fins per inch (mm) o.c.
- f. Make and model number.
- g. Face area in sq. ft. (sq. m).
- h. Tube size in NPS (DN).
- i. Tube and fin materials.
- j. Circuiting arrangement.

2. Test Data (Indicated and Actual Values):

- a. Airflow rate in cfm (L/s).
- b. Average face velocity in fpm (m/s).
- c. Air pressure drop in inches wg (Pa).
- d. Outside-air, wet- and dry-bulb temperatures in deg F (deg C).
- e. Return-air, wet- and dry-bulb temperatures in deg F (deg C).
- f. Entering-air, wet- and dry-bulb temperatures in deg F (deg C).
- g. Leaving-air, wet- and dry-bulb temperatures in deg F (deg C).
- h. Water flow rate in gpm (L/s).
- i. Water pressure differential in feet of head or psig (kPa).
- j. Entering-water temperature in deg F (deg C).
- k. Leaving-water temperature in deg F (deg C).
- l. Refrigerant expansion valve and refrigerant types.
- m. Refrigerant suction pressure in psig (kPa).
- n. Refrigerant suction temperature in deg F (deg C).
- o. Inlet steam pressure in psig (kPa).

I. Gas- and Oil-Fired Heat Apparatus Test Reports: In addition to manufacturer's factory startup equipment reports, include the following:

1. Unit Data:

- a. System identification.
- b. Location.

- c. Make and type.
    - d. Model number and unit size.
    - e. Manufacturer's serial number.
    - f. Fuel type in input data.
    - g. Output capacity in Btuh (kW).
    - h. Ignition type.
    - i. Burner-control types.
    - j. Motor horsepower and rpm.
    - k. Motor volts, phase, and hertz.
    - l. Motor full-load amperage and service factor.
    - m. Sheave make, size in inches (mm), and bore.
    - n. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
  - 2. Test Data (Indicated and Actual Values):
    - a. Total airflow rate in cfm (L/s).
    - b. Entering-air temperature in deg F (deg C).
    - c. Leaving-air temperature in deg F (deg C).
    - d. Air temperature differential in deg F (deg C).
    - e. Entering-air static pressure in inches wg (Pa).
    - f. Leaving-air static pressure in inches wg (Pa).
    - g. Air static-pressure differential in inches wg (Pa).
    - h. Low-fire fuel input in Btuh (kW).
    - i. High-fire fuel input in Btuh (kW).
    - j. Manifold pressure in psig (kPa).
    - k. High-temperature-limit setting in deg F (deg C).
    - l. Operating set point in Btuh (kW).
    - m. Motor voltage at each connection.
    - n. Motor amperage for each phase.
    - o. Heating value of fuel in Btuh (kW).
- J. Electric-Coil Test Reports: For electric furnaces, duct coils, and electric coils installed in central-station air-handling units, include the following:
- 1. Unit Data:
    - a. System identification.
    - b. Location.
    - c. Coil identification.
    - d. Capacity in Btuh (kW).
    - e. Number of stages.
    - f. Connected volts, phase, and hertz.
    - g. Rated amperage.
    - h. Airflow rate in cfm (L/s).
    - i. Face area in sq. ft. (sq. m).
    - j. Minimum face velocity in fpm (m/s).
  - 2. Test Data (Indicated and Actual Values):
    - a. Heat output in Btuh (kW).
    - b. Airflow rate in cfm (L/s).
    - c. Air velocity in fpm (m/s).

- d. Entering-air temperature in deg F (deg C).
  - e. Leaving-air temperature in deg F (deg C).
  - f. Voltage at each connection.
  - g. Amperage for each phase.
- K. Fan Test Reports: For supply, return, and exhaust fans, include the following:
  - 1. Fan Data:
    - a. System identification.
    - b. Location.
    - c. Make and type.
    - d. Model number and size.
    - e. Manufacturer's serial number.
    - f. Arrangement and class.
    - g. Sheave make, size in inches (mm), and bore.
    - h. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
  - 2. Motor Data:
    - a. Make and frame type and size.
    - b. Horsepower and rpm.
    - c. Volts, phase, and hertz.
    - d. Full-load amperage and service factor.
    - e. Sheave make, size in inches (mm), and bore.
    - f. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
    - g. Number of belts, make, and size.
  - 3. Test Data (Indicated and Actual Values):
    - a. Total airflow rate in cfm (L/s).
    - b. Total system static pressure in inches wg (Pa).
    - c. Fan rpm.
    - d. Discharge static pressure in inches wg (Pa).
    - e. Suction static pressure in inches wg (Pa).
- L. Round, Flat-Oval, and Rectangular Duct Traverse Reports: Include a diagram with a grid representing the duct cross-section and record the following:
  - 1. Report Data:
    - a. System and air-handling unit number.
    - b. Location and zone.
    - c. Traverse air temperature in deg F (deg C).
    - d. Duct static pressure in inches wg (Pa).
    - e. Duct size in inches (mm).
    - f. Duct area in sq. ft. (sq. m).
    - g. Indicated airflow rate in cfm (L/s).
    - h. Indicated velocity in fpm (m/s).
    - i. Actual airflow rate in cfm (L/s).
    - j. Actual average velocity in fpm (m/s).
    - k. Barometric pressure in psig (Pa).



M. Air-Terminal-Device Reports:

1. Unit Data:
  - a. System and air-handling unit identification.
  - b. Location and zone.
  - c. Test apparatus used.
  - d. Area served.
  - e. Air-terminal-device make.
  - f. Air-terminal-device number from system diagram.
  - g. Air-terminal-device type and model number.
  - h. Air-terminal-device size.
  - i. Air-terminal-device effective area in sq. ft. (sq. m).
2. Test Data (Indicated and Actual Values):
  - a. Airflow rate in cfm (L/s).
  - b. Air velocity in fpm (m/s).
  - c. Preliminary airflow rate as needed in cfm (L/s).
  - d. Preliminary velocity as needed in fpm (m/s).
  - e. Final airflow rate in cfm (L/s).
  - f. Final velocity in fpm (m/s).
  - g. Space temperature in deg F (deg C).

N. System-Coil Reports: For reheat coils and water coils of terminal units, include the following:

1. Unit Data:
  - a. System and air-handling unit identification.
  - b. Location and zone.
  - c. Room or riser served.
  - d. Coil make and size.
  - e. Flowmeter type.
2. Test Data (Indicated and Actual Values):
  - a. Airflow rate in cfm (L/s).
  - b. Entering-water temperature in deg F (deg C).
  - c. Leaving-water temperature in deg F (deg C).
  - d. Water pressure drop in feet of head or psig (kPa).
  - e. Entering-air temperature in deg F (deg C).
  - f. Leaving-air temperature in deg F (deg C).

O. Compressor and Condenser Reports: For refrigerant side of unitary systems, stand-alone refrigerant compressors, air-cooled condensing units, or water-cooled condensing units, include the following:

1. Unit Data:
  - a. Unit identification.
  - b. Location.
  - c. Unit make and model number.

- d. Compressor make.
- e. Compressor model and serial numbers.
- f. Refrigerant weight in lb (kg).
- g. Low ambient temperature cutoff in deg F (deg C).

2. Test Data (Indicated and Actual Values):

- a. Inlet-duct static pressure in inches wg (Pa).
- b. Outlet-duct static pressure in inches wg (Pa).
- c. Entering-air, dry-bulb temperature in deg F (deg C).
- d. Leaving-air, dry-bulb temperature in deg F (deg C).
- e. Condenser entering-water temperature in deg F (deg C).
- f. Condenser leaving-water temperature in deg F (deg C).
- g. Condenser-water temperature differential in deg F (deg C).
- h. Condenser entering-water pressure in feet of head or psig (kPa).
- i. Condenser leaving-water pressure in feet of head or psig (kPa).
- j. Condenser-water pressure differential in feet of head or psig (kPa).
- k. Control settings.
- l. Unloader set points.
- m. Low-pressure-cutout set point in psig (kPa).
- n. High-pressure-cutout set point in psig (kPa).
- o. Suction pressure in psig (kPa).
- p. Suction temperature in deg F (deg C).
- q. Condenser refrigerant pressure in psig (kPa).
- r. Condenser refrigerant temperature in deg F (deg C).
- s. Oil pressure in psig (kPa).
- t. Oil temperature in deg F (deg C).
- u. Voltage at each connection.
- v. Amperage for each phase.
- w. Kilowatt input.
- x. Crankcase heater kilowatt.
- y. Number of fans.
- z. Condenser fan rpm.
- aa. Condenser fan airflow rate in cfm (L/s).
- bb. Condenser fan motor make, frame size, rpm, and horsepower.
- cc. Condenser fan motor voltage at each connection.
- dd. Condenser fan motor amperage for each phase.

P. Cooling Tower or Condenser Test Reports: For cooling towers or condensers, include the following:

1. Unit Data:

- a. Unit identification.
- b. Make and type.
- c. Model and serial numbers.
- d. Nominal cooling capacity in tons (kW).
- e. Refrigerant type and weight in lb (kg).
- f. Water-treatment chemical feeder and chemical.
- g. Number and type of fans.
- h. Fan motor make, frame size, rpm, and horsepower.
- i. Fan motor voltage at each connection.

- j. Sheave make, size in inches (mm), and bore.
  - k. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
  - l. Number of belts, make, and size.
  - m. Pump make and model number.
  - n. Pump manufacturer's serial number.
  - o. Pump motor make and frame size.
  - p. Pump motor horsepower and rpm.
2. Pump Test Data (Indicated and Actual Values):
- a. Voltage at each connection.
  - b. Amperage for each phase.
  - c. Water flow rate in gpm (L/s).
3. Water Test Data (Indicated and Actual Values):
- a. Entering-water temperature in deg F (deg C).
  - b. Leaving-water temperature in deg F (deg C).
  - c. Water temperature differential in deg F (deg C).
  - d. Entering-water pressure in feet of head or psig (kPa).
  - e. Leaving-water pressure in feet of head or psig (kPa).
  - f. Water pressure differential in feet of head or psig (kPa).
  - g. Water flow rate in gpm (L/s).
  - h. Bleed water flow rate in gpm (L/s).
4. Air Data (Indicated and Actual Values):
- a. Duct airflow rate in cfm (L/s).
  - b. Inlet-duct static pressure in inches wg (Pa).
  - c. Outlet-duct static pressure in inches wg (Pa).
  - d. Average entering-air, wet-bulb temperature in deg F (deg C).
  - e. Average leaving-air, wet-bulb temperature in deg F (deg C).
  - f. Ambient wet-bulb temperature in deg F (deg C).
- Q. Heat-Exchanger/Converter Test Reports: For steam and hot-water heat exchangers, include the following:
1. Unit Data:
- a. Unit identification.
  - b. Location.
  - c. Service.
  - d. Make and type.
  - e. Model and serial numbers.
  - f. Ratings.
2. Steam Test Data (Indicated and Actual Values):
- a. Inlet pressure in psig (kPa).
  - b. Condensate flow rate in lb/h (kW).
3. Primary Water Test Data (Indicated and Actual Values):

- a. Entering-water temperature in deg F (deg C).
  - b. Leaving-water temperature in deg F (deg C).
  - c. Entering-water pressure in feet of head or psig (kPa).
  - d. Water pressure differential in feet of head or psig (kPa).
  - e. Water flow rate in gpm (L/s).
4. Secondary Water Test Data (Indicated and Actual Values):
- a. Entering-water temperature in deg F (deg C).
  - b. Leaving-water temperature in deg F (deg C).
  - c. Entering-water pressure in feet of head or psig (kPa).
  - d. Water pressure differential in feet of head or psig (kPa).
  - e. Water flow rate in gpm (L/s).
- R. Pump Test Reports: Calculate impeller size by plotting the shutoff head on pump curves and include the following:
1. Unit Data:
- a. Unit identification.
  - b. Location.
  - c. Service.
  - d. Make and size.
  - e. Model and serial numbers.
  - f. Water flow rate in gpm (L/s).
  - g. Water pressure differential in feet of head or psig (kPa).
  - h. Required net positive suction head in feet of head or psig (kPa).
  - i. Pump rpm.
  - j. Impeller diameter in inches (mm).
  - k. Motor make and frame size.
  - l. Motor horsepower and rpm.
  - m. Voltage at each connection.
  - n. Amperage for each phase.
  - o. Full-load amperage and service factor.
  - p. Seal type.
2. Test Data (Indicated and Actual Values):
- a. Static head in feet of head or psig (kPa).
  - b. Pump shutoff pressure in feet of head or psig (kPa).
  - c. Actual impeller size in inches (mm).
  - d. Full-open flow rate in gpm (L/s).
  - e. Full-open pressure in feet of head or psig (kPa).
  - f. Final discharge pressure in feet of head or psig (kPa).
  - g. Final suction pressure in feet of head or psig (kPa).
  - h. Final total pressure in feet of head or psig (kPa).
  - i. Final water flow rate in gpm (L/s).
  - j. Voltage at each connection.
  - k. Amperage for each phase.
- S. Air-to-Air Heat-Recovery Unit Reports:

1. Unit Data:
  - a. Unit identification.
  - b. Location.
  - c. Service.
  - d. Make and type.
  - e. Model and serial numbers.
2. Motor Data:
  - a. Make and frame type and size.
  - b. Horsepower and rpm.
  - c. Volts, phase, and hertz.
  - d. Full load amperage and service factor.
  - e. Sheave make, size in inches (mm), and bore.
  - f. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
3. If fans are an integral part of the unit, include the following for each fan:
  - a. Make and type.
  - b. Arrangement and size.
  - c. Sheave make, size in inches (mm), and bore.
  - d. Sheave dimensions, center-to-center, and amount of adjustments in inches (mm).
4. Test Data (Indicated and Actual Values):
  - a. Total exhaust airflow rate in cfm (L/s).
  - b. Purge exhaust airflow rate in cfm (L/s).
  - c. Outside airflow rate in cfm (L/s).
  - d. Total exhaust fan static pressure in inches wg (Pa).
  - e. Total outside-air fan static pressure in inches wg (Pa).
  - f. Pressure drop on each side of recovery wheel in inches wg (Pa).
  - g. Exhaust air temperature entering in deg F (deg C).
  - h. Exhaust air temperature leaving in deg F (deg C).
  - i. Outside-air temperature entering in deg F (deg C).
  - j. Outside-air temperature leaving in deg F (deg C).
  - k. Calculate sensible and total heat capacity of each airstream in MBh (kW).
- T. Vibration Measurement Reports:
  1. Date and time of test.
  2. Vibration meter manufacturer, model number, and serial number.
  3. Equipment designation, location, equipment, speed, motor speed, and motor horsepower.
  4. Diagram of equipment showing the vibration measurement locations.
  5. Measurement readings for each measurement location.
  6. Calculate isolator efficiency using measurements taken.
  7. Description of predominant vibration source.
- U. Sound Measurement Reports: Record sound measurements on octave band and dBA test forms and on an NC or RC chart indicating the decibel level measured in each frequency band

for both "background" and "HVAC system operating" readings. Record each tested location on a separate NC or RC chart. Record the following on the forms:

1. Date and time of test. Record each tested location on its own NC curve.
2. Sound meter manufacturer, model number, and serial number.
3. Space location within the building including floor level and room number.
4. Diagram or color photograph of the space showing the measurement location.
5. Time weighting of measurements, either fast or slow.
6. Description of the measured sound: steady, transient, or tonal.
7. Description of predominant sound source.

V. Indoor-Air Quality Measurement Reports for Each HVAC System:

1. HVAC system designation.
2. Date and time of test.
3. Outdoor temperature, relative humidity, wind speed, and wind direction at start of test.
4. Room number or similar description for each location.
5. Measurements at each location.
6. Observed deficiencies.

W. Instrument Calibration Reports:

1. Report Data:
  - a. Instrument type and make.
  - b. Serial number.
  - c. Application.
  - d. Dates of use.
  - e. Dates of calibration.

### 3.27 INSPECTIONS

A. Initial Inspection:

1. After testing and balancing are complete, operate each system and randomly check measurements to verify that the system is operating according to the final test and balance readings documented in the Final Report.
2. Randomly check the following for each system:
  - a. Measure airflow of at least 10 percent of air outlets.
  - b. Measure water flow of at least 5 percent of terminals.
  - c. Measure room temperature at each thermostat/temperature sensor. Compare the reading to the set point.
  - d. Measure sound levels at two locations.
  - e. Measure space pressure of at least 10 percent of locations.
  - f. Verify that balancing devices are marked with final balance position.
  - g. Note deviations to the Contract Documents in the Final Report.

B. Final Inspection:

1. After initial inspection is complete and evidence by random checks verifies that testing and balancing are complete and accurately documented in the final report, request that a final inspection be made by **Owner**.
2. TAB firm test and balance engineer shall conduct the inspection in the presence of **Owner**.
3. **Owner** shall randomly select measurements documented in the final report to be rechecked. The rechecking shall be limited to either 10 percent of the total measurements recorded, or the extent of measurements that can be accomplished in a normal 8-hour business day.
4. If the rechecks yield measurements that differ from the measurements documented in the final report by more than the tolerances allowed, the measurements shall be noted as "FAILED."
5. If the number of "FAILED" measurements is greater than 10 percent of the total measurements checked during the final inspection, the testing and balancing shall be considered incomplete and shall be rejected.
6. TAB firm shall recheck all measurements and make adjustments. Revise the final report and balancing device settings to include all changes and resubmit the final report.
7. Request a second final inspection. If the second final inspection also fails, Owner shall contract the services of another TAB firm to complete the testing and balancing in accordance with the Contract Documents and deduct the cost of the services from the final payment.

### **3.28 ADDITIONAL TESTS**

- A. Within 90 days of completing TAB, perform additional testing and balancing to verify that balanced conditions are being maintained throughout and to correct unusual conditions.
- B. Seasonal Periods: If initial TAB procedures were not performed during near-peak summer and winter conditions, perform additional testing, inspecting, and adjusting during near-peak summer and winter conditions.

### **END OF SECTION**