

SECTION 230593 - 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 testing, adjusting and balancing HVAC systems to provide design conditions as indicated by the associated drawings. This Section includes, but is not limited to the following:
 - 1. Testing, adjusting and balancing of air and hydronic system fluid flow rates at the system and distribution system level to the indicated quantities according to tolerances specified herein. The following systems to be included:
 - a. Air Systems:
 - 1) Constant-volume air systems.
 - 2) Variable-air-volume systems.
 - 3) Multizone systems.
 - 4) Induction-unit systems.
 - b. Hydronic Piping Systems:
 - 1) Constant-flow hydronic systems.
 - 2) Variable-flow hydronic systems.
 - 3) Primary-secondary hydronic systems.
 - 2. Measuring the electrical performance of HVAC equipment.
 - 3. Verification that automatic control devices are functioning properly.
 - 4. Measurement of sound levels as related to rotating mechanical equipment.
 - 5. Vibration testing and analysis of all rotating equipment greater than or equal to 10 hp.
 - 6. Measurement of duct leakage.
 - 7. Reporting results of the activities and procedures specified in this Section.
- B. The testing, adjusting and balancing of the air and hydronic systems shall be performed by an independent TAB contractor contracted directly by the Owner.

1.3 DEFINITIONS

- A. AABC: Associated Air Balance Council.

- B. Adjust: To regulate fluid flow rates and air patterns at the system or terminal level. At the system level an example would be reducing fan speed; at the terminal level an example would be changing a damper position.
- C. Balance: To proportion air or water flows within the distribution system, including submains, branches and terminals with respect to design quantities.
- 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by one or more factors of high air velocity, low ambient temperature, or direction of airflow, whereby more heat is withdrawn from a person's skin than is normally dissipated.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. Independent: Not affiliated with or in employment of any Contractor.
- F. NEBB: National Environmental Balancing Bureau.
- G. Procedure: An approach to and execution of a sequence of work operations to yield repeatable results.
- H. Report Forms: Test data sheets for recording test data in logical order.
- I. 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.
- J. Suction Head: The height of fluid surface above the centerline of the pump on the suction side.
- K. System Effect: A phenomenon that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system.
- L. 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.
- M. TAB: Testing, adjusting, and balancing.
- N. TABB: Testing, Adjusting, and Balancing Bureau.
- O. TAB Specialist: An entity engaged to perform TAB Work.
- P. Testing, Adjusting and Balancing (TAB) Agent: The entity responsible for performing and reporting the TAB procedures.
- Q. Terminal: A point where the controlled medium (fluid or energy) enters or leaves the distribution system.

1.4 ACTION SUBMITTALS

- A. LEED Submittal:

1. Air-Balance Report for LEED Prerequisite IEQ 1: Documentation of work performed for ASHRAE 62.1, Section 7.2.2, "Air Balancing."
2. TAB Report for Prerequisite EA 2: Documentation of work performed for ASHRAE/IESNA 90.1, Section 6.7.2.3 – "System Balancing."

1.5 INFORMATIONAL SUBMITTALS

Coordinate timing of submittals with Division 01 Sections "Construction Progress Documentation" and "Submittal Procedures."

- A. Contract Documents Examination Report: Within 30 days of Contractor's Notice to Proceed, submit the Contract Documents review report as specified in Part 3.
- B. Strategies and Procedures Plan: Within 60 days of Contractor's Notice to Proceed and prior to commencing work, submit TAB strategies and step-by-step procedures as specified in "Preparation" Article.
- C. Certified TAB reports.
- D. Sample report forms, other than those standard forms from AABC, NEBB or TABB.
- E. List of instruments and associated calibration reports to be used on project; at a minimum, this shall include the following information:
 1. Instrument type and make (manufacturer and model number).
 2. Serial number.
 3. Application.
 4. Dates of use.
 5. Dates of calibration.

1.6 QUALITY ASSURANCE

- A. Agent shall be an independent testing, adjusting and balancing professional services provider certified by AABC or NEBB and have a minimum of five years experience on projects of similar scope and complexity (unless waived by MSU Infrastructure Planning and Facilities / Planning, Design and Construction). Approved TAB Agent shall be considered from the following:
 1. Absolut Balancing Company – South Lyon, MI.
 2. Aerodynamics Inspecting Company – Dearborne, MI.
 3. Air Flow Testing, Inc. – Lincoln Park, MI.
 4. Enviro-Aire/Total Balance, Inc. – St. Clair Shores, MI.
 5. Ener-Tech Testing, Holly, MI.
 6. Hi-Tech Test and Balance – Freeland, MI.
 7. International Test and Balance – Southfield, MI.
 8. Mechanical Testing Services, Inc. – Grandville, MI.
 9. Quality Air Service – Kalamazoo, MI.

- B. TAB Conference: Meet with [MSU Commissioning Services / Commissioning Authority / MSU Planning, Design and Construction] on approval of the TAB strategies and procedures plan. This will be carried out to develop a mutual understanding of the requirements for system configuration and scheduling. Require the participation of the TAB field supervisor, TAB technicians mechanical contractor, electrical contractor and controls contractor. Provide seven days' advance notice of scheduled meeting time and location.
1. Agenda Items:
 - a. The Contract Documents examination report.
 - b. The TAB plan.
 - c. Coordination and cooperation of trades and subcontractors.
 - d. Coordination of documentation and communication flow.
- C. Certify TAB field data reports and perform the following:
1. Review field data reports to validate accuracy of data and to prepare certified TAB reports.
 2. Certify that the TAB team complied with the approved TAB plan and the procedures specified and referenced in this Specification.
- D. TAB Report Forms: Use standard TAB contractor's forms approved by Commissioning Authority.
- E. Instrumentation Type, Quantity, Accuracy, and Calibration: As described in ASHRAE 111, Section 5, "Instrumentation."

Retain "ASHRAE Compliance" Paragraph below for LEED Prerequisite IEQ 1, which requires compliance with ASHRAE 62.1.

- F. ASHRAE Compliance: Applicable requirements in ASHRAE 62.1, Section 7.2.2 – "Air Balancing."

Retain "ASHRAE/IESNA Compliance" Paragraph below for LEED Prerequisite EA 2, which requires compliance with ASHRAE/IESNA 90.1.

- G. ASHRAE/IESNA Compliance: Applicable requirements in ASHRAE/IESNA 90.1, Section 6.7.2.3 – "System Balancing."

1.7 PROJECT CONDITIONS

Retain one of two paragraphs below. Delete article if there will be no occupancy during TAB Work.

- A. Full Owner Occupancy: Owner will occupy the site and existing building during entire TAB period. Cooperate with [MSU PDC Project Representative / Owner] during TAB operations to minimize conflicts with Owner's operations.

Retain paragraph below if Owner might occupy completed areas of building.

- B. Partial Owner Occupancy: Owner may occupy completed areas of building before Substantial Completion. Cooperate with [MSU PDC Project Representative / Owner] during TAB operations to minimize conflicts with Owner's operations.

1.8 COORDINATION

- A. Provide seven days' advance notice for each test. Include scheduled test dates and times.
- B. Perform TAB after leakage and pressure tests on air and water distribution systems have been satisfactorily completed.
- C. Systems shall be fully operational prior to system balancing. If a commissioning program is in place, all startup, testing and verification (STV) procedures shall be complete prior to initiation of TAB activities.
- D. Test, adjust, and balance the air systems before hydronic systems.

Include the first paragraph below only for LEED certified projects requiring Enhanced Commissioning.

- E. Design Review: Provide one design review at final construction document review phase in order to point out monitoring and instrumentation requirements for proper system balance.
- F. Construction Review: Provide onsite visit upon either completion of a commissioning program start-up phase or 100% controls completion and full system operability. Submit a "Systems Ready To TAB" checklist to [MSU CxS/CxA / MSU PDC] for completion by the appropriate installing contractors.
- G. The mechanical contractor shall complete the installation and start all HVAC systems to ensure they are working properly, and shall perform all other items to assist the TAB contractor in performing the testing, adjusting, and balancing of the HVAC systems. Completion of a Systems Ready To TAB" checklist is required by the appropriate installing contractor prior to the beginning of TAB.
- H. The mechanical contractor shall make any necessary changes to the impellers, motors, sheaves, belts, dampers as required by the TAB contractor at no additional cost to the owner. Adjustable pitch sheaves shall be replaced with fixed pitch sheaves after completing system balancing. Replaced sheaves and belts shall be disposed of by mechanical contractor.
- I. The temperature control contractor shall complete the installation, and operate and test all control systems to ensure they are functioning properly as designed. The temperature control contractor shall assist the TAB contractor as needed to verify the operation and calibration of all temperature control systems. Completion of a Systems Ready To TAB" checklist is required by the appropriate installing contractor prior to the beginning of TAB.
- J. Demonstration of mechanical equipment shall be performed by the mechanical contractor, or by factory trained manufacturer's representative as specified.
- K. Provide instruments and technicians as required to verify readings under direction of [MSU Commissioning Services / Commissioning Authority]

PART 2 - PRODUCTS (Not Applicable)

PART 3 - EXECUTION

3.1 TEST EQUIPMENT

- A. Instrumentation shall be provided as necessary and appropriate to perform the work. The instrument shall be factory calibrated, and shall be used with the factory-determined application factors. When reasonable doubt of accuracy exists, recalibration of any or all instrumentation shall be performed as requested by the Commissioning Authority.
- B. Proprietary test equipment shall be provided by the manufacturer of the equipment. The manufacturer's representative shall provide the equipment, demonstrate use of the equipment, and assist the TAB contractor or Commissioning Authority in the testing process.
- C. Make instruments available to the [MSU Commissioning Services /Commissioning Authority] to facilitate TAB data verification during testing.
- D. Test pressure taps, pressure gages, thermometers and wells shall be installed by the mechanical contractor as indicated or specified.
- E. Flow measuring stations, flow-limiting devices and balancing valves shall be installed by the mechanical contractor as indicated or specified.
- F. All manual volume dampers located above ceilings shall be outfitted with a ribbon of consistent color and type and installed by mechanical contractor for facilitation of locating dampers during TAB.
- G. Any additional required pressure and flow taps, and thermometer wells in locations where permanent installation devices are not indicated or specified shall be provided by the mechanical contractor.

3.2 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.
- B. Examine systems for installed balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers. Verify that locations of these balancing devices are accessible.
- C. Examine the approved submittals for HVAC systems and equipment.
- 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 ceiling plenums and underfloor air plenums used for supply, return, or relief air to verify that they meet the leakage class of connected ducts as specified in Division 23 Section "Metal Ducts" and are properly separated from adjacent areas. Verify that penetrations in plenum walls are sealed and fire-stopped if required.
- F. Examine equipment performance data including fan and pump curves.
 - 1. 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.
 - 2. Calculate system-effect factors to reduce performance ratings of HVAC equipment when installed under conditions different from the conditions used to rate equipment performance. To calculate system effects for air systems, use tables and charts found in AMCA 201, "Fans and Systems," or in SMACNA's "HVAC Systems - Duct Design." Compare results with the design data and installed conditions.
- G. Examine system and equipment installations and verify that field quality-control testing, cleaning, and adjusting specified in individual Sections have been performed.
- H. Examine test reports specified in individual system and equipment Sections.
- I. Examine HVAC equipment and filters and verify that bearings are greased, belts are aligned and tight, and equipment with functioning controls is ready for operation.
- J. Examine terminal units, such as variable-air-volume boxes, and verify that they are accessible and their controls are connected and functioning.
- K. Examine strainers. Verify that mechanical contractor has replaced startup screens with permanent screens having indicated perforations.
- L. Examine three-way valves for proper installation for their intended function of diverting or mixing fluid flows.
- M. Examine heat-transfer coils for correct piping connections and for clean and straight fins.
- N. Examine system pumps to ensure absence of entrained air in the suction piping; mechanical contractor to assist as necessary.
- O. Temperature controls contractor shall aid in the examination of operating safety interlocks and controls on HVAC equipment.
- P. Report deficiencies discovered before and during performance of TAB procedures to [MSU Commissioning Services / MSU PDC / the Commissioning Authority]. Observe and record system reactions to changes in conditions. Record default set points if different from indicated values.

3.3 PREPARATION

- A. Prepare a TAB plan that includes strategies and step-by-step procedures.
- B. Procedure shall include a project specific approach which integrates general methods as set forth by the AABC as per National Standards for Total System Balance and/or NEBB as per Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems.
- C. Verify completion of the "Systems Ready to TAB" report. It shall include the following items:
 - 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.

3.4 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 Total System Balance", ASHRAE 111, NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems" or SMACNA's "HVAC Systems - Testing, Adjusting, and Balancing" and in this Section.

LEED Prerequisite IEQ 1 requires compliance with requirements in ASHRAE 62.1, Section 7.2.2, "Air Balancing." ASHRAE 62.1 requires that ventilation systems be balanced according to ASHRAE 111, SMACNA's "HVAC Systems - Testing, Adjusting, and Balancing," or equivalent at least to extent necessary to verify compliance with the standard.

- 1. Comply with requirements in ASHRAE 62.1, Section 7.2.2, "Air Balancing."
- B. Cut insulation, ducts, pipes, and equipment cabinets for installation of test probes to the minimum extent necessary for TAB procedures.
 - 1. After testing and balancing, the mechanical contractor shall install test ports and duct access doors that comply with requirements in Division 23 Section "Air Duct Accessories."
 - 2. Install and join new insulation that matches removed materials. Restore insulation, coverings, vapor barrier, and finish according to Division 23 Section "HVAC Insulation."
- C. Mark equipment and balancing devices, including damper-control positions, valve position indicators, fan-speed-control levers, and similar controls and devices, with paint or other suitable, permanent identification material to show final settings.

- D. Note in report, as applicable, all final settings of variable frequency drives for specified design conditions, the associated static pressures/differential pressures observed and the conditions under which the system was tested, adjusted and balanced.
- E. Take and report testing and balancing measurements in inch-pound (IP) units.

3.5 GENERAL PROCEDURES FOR BALANCING AIR SYSTEMS

- 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 as applicable. This plan shall be discussed and agreed upon with [MSU Commissioning Services / MSU PDC / the Commissioning Authority]. The final plan for diversity shall be reflected in the report by which it pertains.
- D. Determine the best locations in main and branch ducts for accurate duct-airflow measurements.
- E. Check airflow patterns from the outdoor-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. Verify that air duct system is sealed as specified in Division 23 Section "Metal Ducts."

3.6 PROCEDURES FOR CONSTANT-VOLUME AIR SYSTEMS

Retain this article if using constant-volume air systems

- A. Adjust fans to deliver total indicated airflows within the maximum allowable fan speed listed by fan manufacturer.
 - 1. Measure total airflow.

- a. Where sufficient space in ducts is unavailable for Pitot-tube traverse measurements, measure airflow at terminal outlets and inlets and calculate the total airflow.
 2. Measure fan static pressures as follows to determine actual static pressure:
 - a. Measure outlet static pressure as far downstream from the fan as practical 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 the 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.
 3. Measure static pressure across each component that makes up an air-handling unit, rooftop unit, and other air-handling and -treating equipment.
 - a. Report the cleanliness status of filters and the time static pressures are measured.
 4. Measure static pressures entering and leaving other devices, such as sound traps, heat-recovery equipment, and air washers, under final balanced conditions.
 5. Review Record Documents to determine variations in design static pressures versus actual static pressures. Calculate actual system-effect factors. Recommend adjustments to accommodate actual conditions.
 6. Obtain approval from Architect for adjustment of fan speed higher or lower than indicated speed. Comply with requirements in Division 23 Sections for air-handling units for adjustment of fans, belts, and pulley sizes to achieve indicated air-handling-unit performance.
 7. Do not make fan-speed adjustments that result in motor overload. Consult equipment manufacturers about fan-speed safety factors. Fan speed shall not be increased in excess of manufacturer's maximum recommended RPM. 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 mode 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 airflow of submain and branch ducts.
 - 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. Measure static pressure at a point downstream from the balancing damper, and adjust volume dampers until the proper static pressure is achieved.
 3. 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 air 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 air outlets and inlets for each space to indicated airflows within specified tolerances of indicated values. Make adjustments using branch 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.

3.7 PROCEDURES FOR VARIABLE-AIR-VOLUME SYSTEMS

Retain this article if using 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 minimum set-point airflow with the remainder at maximum-airflow condition until the total airflow of the terminal units equals the indicated airflow of the fan. Discuss plan to simulate diversity with [MSU CxS/CxA and MSU PDC] and document agreed upon procedure prior to beginning work.
- B. Pressure-Independent, Variable-Air-Volume Systems: After the fan systems have been adjusted, adjust the variable-air-volume systems as follows:
 - 1. Set outdoor-air dampers at minimum, and set 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 the 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. Coordinate with temperature control contractor to calibrate any airflow measuring devices installed in the air-handling systems. 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 the same 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 the same 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. Re-measure the return airflow to the fan while operating at maximum return airflow and minimum outdoor airflow.
 - a. Adjust the fan and balance the return-air ducts and inlets the same as described for constant-volume air systems.
 7. Upon completion of the above scope of work, place all variable air terminal units to full cooling mode, 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. At this time, coordinate with the temperature controls contractor to verify that all variable air terminal unit dampers, namely the critical terminal unit damper, are near but less than 100% open. Adjust system to achieve this condition therefore optimizing energy consumption and validating design airflow conditions during requirements for full load.
 8. Record 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 variable-air-volume systems the same as described for 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 the same 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.
- Retain first subparagraph below if using 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 the same 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 outdoor airflow.
 - a. Adjust the fan and balance the return-air ducts and inlets the same 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 the same 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 outdoor airflow. Adjust the fan and balance the return-air ducts and inlets the same as described for constant-volume air systems.

3.8 PROCEDURES FOR MULTIZONE SYSTEMS

- A. Set unit at maximum airflow through the cooling coil.
- B. The outside air (OA) and return air (RA) dampers should be postured prior to balancing. If the air handling unit (AHU) has a fixed OA damper it should be set to the appropriate position as a starting point.
- C. The OA damper for air handling units using mechanical cooling should be adjusted to a position estimated to equal the design minimum airflow.
- D. The OA damper for units using only ventilation air for cooling should be positioned 100% open, with the RA dampers closed.
- E. If the cooling coil is sized for the full fan airflow, put all zones into full cooling by setting each zone thermostat to the lowest point.
- F. Measure airflow of each zone and total the results.
- G. Make any required fan speed adjustments to obtain the design total airflow.
- H. Adjust each zone's balancing damper to achieve indicated airflow within the zone. This type of system cannot be properly balanced without manual zone balancing dampers. If the dampers are not provided, the TAB Supervisor should notify [MSU CxS / MSU PDC / CxA] to have them installed.
- I. Once each zone has the correct airflow, the outlets can be balanced by using the previously described methods.
- J. At the conclusion of all inlet and outlet balancing, re-adjust the AHU minimum OA ventilation rate, if required.

- K. Record final unit data, prepare the report forms, and submit as required.

3.9 PROCEDURES FOR INDUCTION-UNIT SYSTEMS

- A. Balance primary-air risers by measuring static pressure at the nozzles of the top and bottom units of each riser to determine which risers must be throttled. Adjust risers to indicated airflow within specified tolerances.
- B. Adjust each induction unit.

3.10 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 the 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 liquid level in expansion tank.
 - 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.

3.11 PROCEDURES FOR CONSTANT-FLOW 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 at maximum RPM 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.
 - a. If impeller sizes must be adjusted to achieve pump performance, obtain approval from Architect and comply with requirements in Division 23 Section "Hydronic Pumps."

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.
 - a. Monitor motor performance during procedures and do not operate motors in overload conditions.
 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 10 percent of design.
- B. Measure flow at all automatic flow control valves to verify that valves are functioning as designed.
- C. Measure flow at all pressure-independent characterized control valves, with valves in fully open position, to verify that valves are functioning as designed.
- D. Set calibrated balancing valves, if installed, at calculated presettings.
- E. 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.
- F. Measure flow at main balancing station and set main balancing device to achieve flow that is 5 percent greater than indicated flow.
- G. 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.
- H. Measure pump flow rate and make final measurements of pump amperage, voltage, rpm, pump heads, and systems' pressures and temperatures including outdoor-air temperature.
- I. Measure the differential-pressure-control-valve settings existing at the conclusion of balancing.
- J. Check settings and operation of each safety valve. Record settings.

3.12 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. Once TAB is complete per the specified procedures above, note the final differential pressure output which indicates the design flow condition. Fully open the metering valve located at the pump discharge. Decrease speed at variable frequency drive until differential pressure matches that originally attained at design conditions.

3.13 PROCEDURES FOR PRIMARY-SECONDARY HYDRONIC SYSTEMS

- A. Balance the primary circuit flow first and then balance the secondary circuits.

3.14 PROCEDURES FOR STEAM SYSTEMS

- A. Measure and record upstream and downstream pressure of each piece of equipment.
- B. Measure and record upstream and downstream steam pressure of pressure-reducing valves.
- C. Check settings and operation of automatic temperature-control valves, self-contained control valves, and pressure-reducing valves. Record final settings.
- D. Check settings and operation of each safety valve. Record settings.
- E. Verify the operation of each steam trap.

3.15 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 settings and operation of safety and relief valves. Record settings.

3.16 PROCEDURES FOR MOTORS

- A. Motors, 1/2 HP and Larger: Test at final balanced conditions and record the following data:
 - 1. Manufacturer's name, model number, and serial number.
 - 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 of the controller to prove proper operation. Record observations including name of controller manufacturer, model number, serial number, and nameplate data.

3.17 PROCEDURES FOR CHILLERS

- A. Balance water flow through each evaporator and condenser to within specified tolerances of indicated flow with all pumps operating. With only one chiller operating in a multiple chiller installation, do not exceed the flow for the maximum tube velocity recommended by the chiller manufacturer. Measure and record the following data with each chiller operating at design conditions:
 - 1. Evaporator-water entering and leaving temperatures, pressure drop, and water flow.
 - 2. For water-cooled chillers, condenser-water entering and leaving temperatures, pressure drop, and water flow.
 - 3. Evaporator and condenser refrigerant temperatures and pressures, using instruments furnished by chiller manufacturer.
 - 4. Power factor if factory-installed instrumentation is furnished for measuring kilowatts.
 - 5. Kilowatt input if factory-installed instrumentation is furnished for measuring kilowatts.
 - 6. Capacity: Calculate in tons of cooling.
 - 7. For air-cooled chillers, verify condenser-fan rotation and record fan and motor data including number of fans and entering- and leaving-air temperatures.

3.18 PROCEDURES FOR COOLING TOWERS

Tests in paragraph below do not comply with CTI STD-105, "Acceptance Test Code." If a CTI test is included in the Section specifying cooling towers, delete this article.

- A. Shut off makeup water for the duration of the test, and verify that makeup and blowdown systems are fully operational after tests and before leaving the equipment. Perform the following tests and record the results:
 - 1. Measure condenser-water flow to each cell of the cooling tower.
 - 2. Measure entering- and leaving-water temperatures.
 - 3. Measure wet- and dry-bulb temperatures of entering air.
 - 4. Measure wet- and dry-bulb temperatures of leaving air.
 - 5. Measure condenser-water flow rate recirculating through the cooling tower.
 - 6. Measure cooling-tower spray pump discharge pressure.
 - 7. Adjust water level and feed rate of makeup water system.
 - 8. Measure flow through bypass.

3.19 PROCEDURES FOR CONDENSING UNITS

- A. Verify proper rotation of fans.
- B. Measure entering- and leaving-air temperatures.

- C. Record compressor data.

3.20 PROCEDURES FOR BOILERS

Retain this article if using boilers.

- A. Hydronic Boilers: Measure and record entering- and leaving-water temperatures and water flow.
- B. Steam Boilers: Measure and record entering-water temperature and flow and leaving-steam pressure, temperature, and flow.

3.21 PROCEDURES FOR HEAT-TRANSFER COILS

Retain this article if using hear-transfer coils.

- A. Measure, adjust, and record the following data for each water 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. Measure, adjust, and record the following data for each electric heating 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. Measure, adjust, and record the following data for each steam coil:
 - 1. Dry-bulb temperature of entering and leaving air.
 - 2. Airflow.
 - 3. Air pressure drop.
 - 4. Inlet steam pressure.
- D. Measure, adjust, and record the following data for each refrigerant 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.

3.22 PROCEDURES FOR TESTING, ADJUSTING, AND BALANCING EXISTING SYSTEMS

Retain this article if Project includes 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 condition of dampers.
 - 7. Verify appropriate location of balancing devices such that accurate measurements can be attained and final TAB can be completed.
 - 8. Check the operation of the drain pan and condensate-drain trap.
 - 9. Check bearings and other lubricated parts for proper lubrication.
 - 10. 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. Verify the following:
 - 1. New filters are installed.
 - 2. Coils are clean and fins combed.
 - 3. Drain pans are clean.
 - 4. Fans are clean.
 - 5. Dampers functioning properly.
 - 6. Verify correct operation of existing measurement/balancing devices (eg, dampers, gauges, valves, etc.)
 - 7. Bearings and other parts are properly lubricated.
 - 8. 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 and the face velocity of filters and coils.
 - 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 air flow rates and water flow rates by more than 5 percent, make equipment adjustments to achieve the calculated rates. If increase or decrease is 5 percent or less, equipment adjustments are not required.
 - 4. Balance each air outlet.

3.23 VIBRATION ANALYSIS [ACCEPTANCE TESTING]

- A. Measurements shall be taken on the bearing caps of the machine in the vertical, horizontal and axial directions or at the equipment mounting feet if bearings are concealed.
- B. For all equipment 10 horsepower and above, the contractor shall provide printed FFT signatures of vibration amplitude versus frequency. The frequency range should be broad enough to include all frequencies characteristic of the equipment, and the frequency filter should not be greater than 10% of band width. At least one signature should be taken on each bearing cap in the radial axis with the highest velocity amplitude. Signatures are to include velocity (inches per second peak to peak) and a bearing condition analysis (acceleration in g's, inches per second squared, under a high band pass filter).
- C. If the self-excited vibration velocity exceeds the allowable maximum, the source of the vibration shall be determined by a qualified vibration consultant. After the source of vibration is determined, corrections shall be made by the Contractor to reduce the self-excited vibration velocity to a level below the allowable maximum.
- D. All vibration measurements and analysis shall be made with instruments traceable to the National Bureau of Standards Criteria such as International Research and Development Corporation (IRD) Microprocessor Analyzer Balancer – Model 880, or approved equal.
- E. Factory certification of vibration velocity of totally assembled unit will be acceptable in lieu of field measurements for packaged air conditioners, including through wall or window air conditioners, and equipment employing fractional horsepower electric motors.
- F. The mechanical contractor shall complete the installation and start of all mechanical systems to ensure they are working properly prior to scheduling the vibration analysis provider.
- G. The mechanical contractor shall be responsible for any necessary changes to fans, fan housings, pumps, pump bases, motors, pipe/duct hanger assemblies as required by the vibration analysis provider at no additional cost to the owner.
- H. Approved vibration testing and analysis provider shall be considered from the following:
 - 1. Reliability Concepts, LLC – Coldwater, MI
 - 2. PMSI – Kalamazoo, MI
 - 3. Zeluff Associates – Kalamazoo, MI

3.24 TOLERANCES

- A. Set HVAC system's air flow rates and water flow rates within the following tolerances:
 - 1. Supply, Return, and Exhaust Fans and Equipment with Fans: Plus or minus 10 percent.
 - 2. Air Outlets and Inlets: Plus or minus 10 percent.
 - 3. Heating-Water Flow Rate: Plus or minus 10 percent.
 - 4. Cooling-Water Flow Rate: Plus or minus 10 percent.

- B. Adjust pumps to within 10% of design GPM at design temperature. Excess pump pressure shall be eliminated by trimming the pump impeller by the Mechanical Contractor (this shall be carried out by the mechanical contractor).
- C. General rotating equipment maximum allowable self-excited, total unfiltered vibration velocity shall not exceed 0.15 inches per second peak to peak. Individual velocity amplitude peaks of filtered readings are not to exceed 0.10 inches per second peak to peak.
- D. Direct drive pump maximum allowable self-excited, total unfiltered vibration velocity shall not exceed 0.10 inches per second peak to peak. Individual velocity amplitude peaks of filtered readings are not to exceed 0.05 inches per second peak to peak.

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. Also, include system schematic diagrams consistently referenced with all equipment and test points, and preliminary test data.
- B. Status Reports: Prepare [weekly] monthly progress 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

Revise contents of reports specified in this article to suit office practice.

- A. General: Prepare a certified written report; tabulate and divide the report into separate sections for tested systems and balanced systems.
 - 1. Upon verification and approval of draft reports, submit 1 complete set of final reports certified by the TAB contractor for the Architect and 2 sets for inclusion in operating and maintenance manuals. Bind report forms complete with schematic diagrams and data in reinforced, vinyl, 3-ring binder manuals.
 - 2. As-built system schematic diagrams consistently referenced with all equipment and test points, and final test data.
 - 3. Include a certification sheet at the front of the report's binder, signed and sealed by the certified testing and balancing engineer.
 - 4. Include a list of instruments used for procedures, along with proof of calibration.
- B. 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; do not include Shop Drawings and product data.

C. General Report Data: In addition to form titles and entries, include the following data:

1. Title page.
2. Name and address of the TAB contractor.
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 supervisor 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's name, type, size, and fittings.
14. Notes to explain why certain final data in the body of reports vary from indicated values.
15. Test conditions for fans and pump performance forms including the following:
 - a. Settings for outdoor-, 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.

D. 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 outdoor, 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.

E. Air-Handling-Unit Test Reports: For air-handling units with coils, include the following:

1. Unit Data:

- 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. Center-to-center dimensions of sheave, and amount of adjustments in inches (mm).
- j. Number, make, and size of belts.
- k. Number, type, and size of filters.

2. Motor Data:

- a. Motor 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. Center-to-center dimensions of sheave, and amount of adjustments in inches (mm).

3. Test Data (Indicated and Actual Values):

- a. Total air flow 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. Outdoor airflow in cfm (L/s); this should be tested in both maximum and minimum conditions.
- j. Return airflow in cfm (L/s); this should be tested in both maximum and minimum outdoor air conditions.
- k. Relief airflow in cfm (L/s); this should be tested in both maximum and minimum outdoor air conditions.
- l. Outdoor-air damper position.
- m. Return-air damper position.
- n. Vortex damper position.
- o. VFD frequency setting (Hz) and final static pressure set point; clearly indicate system configuration during testing.
- p. Calibration of airflow stations (any that exist on the air-handling unit).

F. 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. Air flow rate in cfm (L/s).
 - b. Average face velocity in fpm (m/s).
 - c. Air pressure drop in inches wg (Pa).
 - d. Outdoor-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).

G. 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 Btu/h (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. Center-to-center dimensions of sheave, and amount of adjustments in inches (mm).
2. Test Data (Indicated and Actual Values):
 - a. Total air flow 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 Btu/h (kW).
 - i. High-fire fuel input in Btu/h (kW).
 - j. Manifold pressure in psig (kPa).
 - k. High-temperature-limit setting in deg F (deg C).
 - l. Operating set point in Btu/h (kW).
 - m. Motor voltage at each connection.
 - n. Motor amperage for each phase.
 - o. Heating value of fuel in Btu/h (kW).
- H. 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. Center-to-center dimensions of sheave, and amount of adjustments in inches (mm).
 2. Motor Data:
 - a. Motor 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. Center-to-center dimensions of sheave, and amount of adjustments in inches (mm).
 - g. Number, make, and size of belts.
 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).
 - f. VFD frequency setting (Hz) and associated 2/3 static pressure reading in inches wg corresponding to design airflow.
- I. 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 air flow rate in cfm (L/s).
 - h. Indicated velocity in fpm (m/s).
 - i. Actual air flow rate in cfm (L/s).
 - j. Actual average velocity in fpm (m/s).
 - k. Barometric pressure in psig (Pa).
 - l. Percent of design achieved.
- J. Air-Terminal-Device Reports:
- 1. Unit Data:
 - a. System and air-handling unit identification.
 - b. Location and zone.
 - c. Apparatus used for test.
 - d. Area served.
 - e. Make.
 - f. Number from system diagram.
 - g. Type and model number.
 - h. Size.
 - i. Effective area in sq. ft. (sq. m).
 - 2. Test Data (Indicated and Actual Values):
 - a. Air flow rate in cfm (L/s).
 - b. Air velocity in fpm (m/s).
 - c. Preliminary air flow rate as needed in cfm (L/s).
 - d. Preliminary velocity as needed in fpm (m/s).
 - e. Final air flow rate in cfm (L/s).
 - f. Final velocity in fpm (m/s).
 - g. Space temperature in deg F (deg C).
 - h. Indicate final flow coefficient.
 - i. Percent of design achieved.
- K. 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. Air flow 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).
 - g. Terminal flow measuring device (circuit setter, flow meter, etc.) make/model/size.
 - h. Terminal flow measuring device water pressure drop (as required to determine terminal unit flow).
 - i. Final setting of flow measuring device valve handle indicator.
 - j. Percent of design achieved.
- L. 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 number and serial number.
 - 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.
- l. Final design flow rate using discharge metering valve (ie triple duty valve, multi-purpose valve) at maximum VFD frequency (Hz); indicate differential pressure in feet of head at design conditions.
- m. Final VFD frequency setting (Hz) and associated 2/3 differential pressure (psig) measurement/set point required to achieve design conditions; clearly indicate system configuration during testing.
- n. Calibration of hydronic flow station(s).

M. 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. 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. Verify that balancing devices are marked with final balance position.
 - e. Note deviations from the Contract Documents in the final report.

B. Final Inspection:

1. After initial inspection is complete and documentation 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 Architect.

2. The TAB contractor's test and balance engineer shall conduct the inspection in the presence of Architect.
 3. Architect shall randomly select measurements, documented in the final report, to be rechecked. 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 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.
- C. TAB Work will be considered defective if it does not pass final inspections. If TAB Work fails, proceed as follows:
1. Recheck all measurements and make adjustments. Revise the final report and balancing device settings to include all changes; resubmit the final report and request a second final inspection.
 2. If the second final inspection also fails, Owner may contract the services of another TAB contractor to complete TAB Work according to the Contract Documents and deduct the cost of the services from the original TAB contractor's final payment.
- D. Prepare test and inspection reports.

3.28 ADDITIONAL TESTS

- A. Within 90 days of completing TAB, perform additional TAB to verify that balanced conditions are being maintained throughout and to correct unusual conditions.

Seasonal balancing test is not required for small HVAC systems. Consult MSU PDC.

- B. Seasonal Periods: If initial TAB procedures were not performed during near-peak summer and winter conditions, perform additional TAB during near-peak summer and winter conditions.

END OF SECTION 230593