**PART 1 – GENERAL**

**1.01 SUMMARY**

A. SECTION INCLUDES

1. This Section specifies the requirements for test and balance of HVAC and related systems.

B. RELATED REQUIREMENTS

1. Section 01 11 00: Summary of Work.

2. Section 01 31 13: Project Coordination.

3. Section 01 32 13: Construction Schedule.

4. Section 01 33 00: Submittal Procedures.

5. Section 01 77 00: Contract Closeout.

6. Section 23 05 00: Common Work Results for HVAC.

7. Section 23 05 13: Basic HVAC Materials and Methods.

8. Section 23 05 48: HVAC Sound, Vibration and Seismic Control.

9. Section 23 09 23: Environmental Control and Energy Management Systems (Only include when DDC Energy Management and Control Systems are provided).

10. Section 23 20 13: Above Ground HVAC Piping.

11. Section 23 20 16: Underground HVAC Piping.

12. Section 23 30 00: Air Distribution.

13. Section 23 38 13: Kitchen Ventilation System.

14. Section 23 5000: Central Heating Equipment.

15. Section 23 64 16: Oil Lubricated Centrifugal Water Chillers.

16. Section 23 64 23: Scroll Water Chillers.

17. Section 23 64 28: Air-Cooled Rotary Screw Chillers.

18. Section 23 65 00: Cooling Towers.

19. Section 23 80 00: Heating, Ventilating and Air Conditioning Equipment.

20. Section 23 8100: Floor Wall Mounted Heat Pumps.

21. Section 28 3149: Carbon Monoxide Detection and Alarm Systems.

**PART 2 – PRODUCTS (Not used)**

**PART 3 – EXECUTION**

**3.01 DEFINITIONS AND APPLICABLE PUBLICATIONS**

A. For the purposes of this Section definitions are as indicated in applicable publications of AABC, NEBB, TABB, ASHRAE, ANSI and SMACNA.

1. TAB: Testing, Adjusting and Balancing.

2. TABB: Testing, Adjusting and Balancing Bureau.

3. AABC: Associated Air Balance Council.

4. NEBB: National Environmental Balancing Bureau.

5. ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

6. ANSI: American National Standards Institute.

7. SMACNA: Sheet Metal and Air Conditioning Contractors’ National Association.

8. OAR: OWNER’S Authorized Representative

**3.02 QUALITY ASSURANCE**

A. The General Contractor shall contract directly with the test and balance agency. Tests performed by testing agencies contracted with the system’s subcontractor will not be accepted. The qualifications of the agency shall comply with Article 3.02, Quality Assurance. The agency shall be responsible for furnishing labor, instruments, and tools required to test, adjust, and balance the heating, ventilating, and air conditioning (HVAC) systems and related plumbing systems, as described and/or as indicated in the Contract Documents.

B. CONTRACTOR shall obtain services of an independent, qualified testing agency acceptable to Architect to perform testing and balancing Work as specified and as follows:

1. Agency shall be currently certified by either the Associated Air Balance Council (AABC), the National Environmental Balancing Bureau (NEBB), or the Testing, Adjusting and Balancing Bureau (TABB). NEBB or TABB certification shall be for Air and Hydronic Testing, Adjusting and Balancing and Sound and Vibration Measurement.

2. Work shall be in accordance with the latest edition of the AABC, NEBB, or TABB National Standards. Where the requirements of the two standards are different, the more stringent requirements shall prevail. Also, if the Contract Documents impose a more stringent standard, then the Contract Documents shall prevail.

C. Performance Criteria: Work of this Section shall be performed in accordance with approved Testing, Adjusting, and Balancing agenda.

D. Test Equipment Criteria: Basic instrumentation requirements and accuracy/calibration required by Section Two of the AABC, Section II of the NEBB, or TABB Procedural Standards for Testing, Adjusting and Balancing of Environmental Systems.

E. Verification: The Test and Balance Agency shall recheck 10 percent (minimum 10) of the measurements listed in the report. The locations shall be selected by PROJECT INSPECTOR or OAR. The recheck will be witnessed by PROJECT INSPECTOR or OAR. If 20 percent of the measurements that are retested differ from the report and are also out of the specified range, an additional 10 percent will be tested. If 20 percent fall outside the specified range, the report will be considered invalid, and all test and balance work shall be repeated.

F. Due to more stringent acoustical requirements in the educational environment, the Test and Balance Agency shall recheck the air systems where the sound level is higher than the specified requirements and demonstrate compliance with the methodology specified in this document with emphasis on fan speed adjustment and balancing for optimum acoustical performance. The recheck will be witnessed by PROJECT INSPECTOR or OAR. When there are multiple air systems, a system selected by PROJECT INSPECTOR or OAR shall be rechecked. If this system is found to be not in compliance, a second system shall be checked. If the second system if also found to be not in compliance, the report will be considered invalid, and all test and balance work shall be repeated.

**3.03 SUBMITTALS**

A. Submit name of agency to perform the Work. Include in the submittal the certified qualifications of all persons responsible for supervising and performing actual Work of this Section. Agency shall submit a minimum of five commercial or industrial HVAC system TAB projects of similar type, size, and degree of difficulty completed within the last two years. Agency shall provide name and telephone number of contact person for each listed project.

B. Submit, for approval, 6 copies of the agenda as indicated in Article 3.06 to test and balance all mechanical and relevant plumbing systems.

C. Preliminary Report: Review the Contract Documents, examine Work installations and submit a written report to ARCHITECT, PROJECT INSPECTOR and OAR indicating deficiencies in Work precluding proper testing and balancing of the Work.

D. Final TAB Report: Submit the final TAB report for review by ARCHITECT, PROJECT INSPECTOR, and OAR outlining the conditions and Work completed on each HVAC system. All outlets, devices, HVAC equipment, etc. shall be identified, along with a numbering system corresponding to report unit identification.

E. Submit an AABC “National Project Performance Guaranty” or “NEBB Quality Assurance Certification”, assuring the Project systems were tested, adjusted, and balanced in accordance with the Specifications and AABC, NEBB, or TABB National Standards.

F. CAD drawings: Submit single line, multi-color CAD drawings indicating outside return and supply air, volume control boxes, each outlet and inlet, room numbers, duct sizes at traverse locations, temperatures and pressures, systems balanced, components changed, and CONTRACTOR installed access points. In addition, drawings shall identify controls, equipment settings, including manual damper quadrant positions, manual valve indicators, fan speed control levers, and similar controls, and devices shall be marked on the drawings to show final settings. CAD files shall be submitted on CD-ROM upon final submittal of TAB report. Reports shall identify discrepancies between completed Work and the Contract Documents affecting the performance and longevity of the system.

**3.04 GENERAL SCOPE OF WORK**

A. The general scope of Work shall include but not be limited to the following:

1. Measure airflow rates of HVAC systems and make adjustments to achieve design airflow rates, tabulate results, and submit reports.

2. Measure water-flow rates of HVAC systems and make adjustments to achieve design water flow rates, tabulate results, and submit reports.

3. Measure flow velocities, temperatures, static pressures or head, rotational speed, and electrical power demand of fans, pumps, and other related HVAC system components, tabulate results, and submit reports.

4. Measure sound levels in each conditioned space, tabulate results, and submit reports.

5. Measure ambient sound levels of outdoor HVAC units and system components such as chillers and cooling towers, tabulate results, and submit reports.

6. Reports shall contain sufficient data for the system designer to evaluate system performance and solve installation problems such as system pressure profiles and pressure drops across system components

**3.05 SPECIFIC SCOPE OF WORK**

A. The specific scope of Work shall include the following HVAC system components as indicated on the Drawings:

1. Air Handling Units.

**EDIT NOTE: EDIT THIS SECTION AND DELETE ITEMS THAT ARE NOT IN THE PROJECT SCOPE OF WORK.**

2. Air Conditioning Units.

3. Heating and Ventilating Units.

4. Heating and Cooling Coils.

5. Supply, Return, Relief and Exhaust Fans.

6. Outside Air and Return Air Plenums.

7. Outside Air Intakes.

8. All Supply and Return Ductwork.

9. All associated Air Terminal Devices, i.e., Supply Diffusers, Return Registers, etc.

10. Mixing Boxes and Variable Air Volume (VAV) boxes.

11. Reheat Coils (Electric or Hot Water).

12. Exhaust Duct Systems.

13. Fire and Fire/Smoke Dampers.

14. Kitchen Hoods.

15. Laboratory Hoods.

16. Heat Exchangers.

17. Chillers.

18. Cooling Towers.

19. Boilers.

20. Chilled water, heating hot water and cooling tower water pumps.

**3.06 TESTING, ADJUSTING, AND BALANCING AGENDA**

A. Provide proposed materials, methods, procedures, forms, diagrams, and reports for test and balance Work.

B. Agenda to be completed by the test and balance agency and submitted to ARCHITECT, PROJECT INSPECTOR, and OAR for review and approval.

C. Agenda shall include one complete set of AABC, NEBB, or TABB publications listed in Sub-paragraph 3.02.B.2, applicable publications, or, in case of other test and balance agencies and or organizations, comparable publications to establish an approved, systematic, and uniform set of procedures.

D. Agenda shall also include the following detailed narrative procedures, system diagrams, and forms for test results:

1. Specific standard procedures required and proposed for each system of the Work.

2. Specified test forms for recording each procedure and for recording sound and vibration measurements.

3. Systems diagrams for each air, water, and steam system. Diagrams may be single line.

E. In addition to information recorded for standard AABC, NEBB, or TABB procedures, the following information is required:

1. Fan data.

2. System number, location, manufacturer, model, and serial number.

3. Fan wheel type and size.

4. Motor horsepower, type, and rpm.

5. Sheave size, type, number of grooves, and open turns on Variable Pitch Sheave.

6. Number and size of belts, motor and fan shaft sizes, center-to-center of shafts in inches, and adjustment available motor data, including nameplate data, actual amps, rated, and actual motor rpm, volts, phase, hp, kW, starter heater size, and capacity.

7. Fan design airflow and service (supply, return, outdoor air or exhaust).

8. Fan static pressure, suction/discharge, static profile, and static control point.

F. The following traverse data is required:

1. Traverse location, size of duct (inside dimensions), and area of duct in square feet.

2. Column for each hole traversed/lines for each reading.

3. Barometric pressure.

4. Temperature/Static pressure in the duct.

5. Actual CFM corrected to SCFM.

6. Notes.

G. The following air distribution data is required:

1. Room identification.

2. Outlet or intake balance sequence number.

3. Size of outlet or inlet.

4. AK Factor.

5. Design and Actual FPM and CFM.

6. Notes.

H. The following hydronic coil data is required:

1. Air flow through the coil in CFM.

2. Dry bulb and wet bulb temperatures entering/leaving coil.

3. Enthalpy or total heat differences in BTU/pound.

4. Capacity in BTU/hour at time of test.

5. Water temperature and pressure entering/leaving coil.

6. Flow (in GPM) through coil.

7. Air pressure drop across coil.

8. Water head drop across coil.

9. Notes.

I. The following DX coil data is required:

1. Air flow through the coil in CFM.

2. Dry and wet bulb temperatures entering/leaving coil.

3. Enthalpy or total heat difference across coil in BTU/ pound.

4. Capacity in BTU/hour at time of test.

5. Air pressure drop across coil.

6. Notes.

J. The following data is required for steam to water heat exchangers for heat and/or domestic generation:

1. Exchanger identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Temperature entering/leaving unit.

4. Flow through unit in GPM.

5. Pressure drop through unit.

6. Entering steam pressure.

7. Notes.

K. The following electric heating coil data is required:

1. Heating coil identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Amperage/Voltage on each phase.

4. Phase, kW, and Stages.

5. Safety device installed.

6. Air pressure drop across coil.

7. Notes.

L. The following water-cooled chiller data is required:

1. Identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Chilled water flow through evaporator in GPM.

4. Water temperature entering/leaving evaporator.

5. Pressure drop through evaporator.

6. Condenser water flow through.

7. Pressure drop through condenser.

8. Water temperature entering/leaving condenser.

9. Motor data, amps, volts, rpm, starter type, overload protection type, phase, hertz, nameplate, and actual measured kW input.

10. Type of refrigerant.

11. Notes.

M. The following cooling tower data is required:

1. Identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Performance test results for rated capacity.

4. Water flow through the tower in GPM.

5. Water temperature entering/leaving tower.

6. Outside Air dry and wet bulb temperatures.

7. Motor data, amps, volts, phase, hertz, and kW input.

8. Starter size and type and heater size and capacity.

9. Water droplets leaving tower - yes/no.

10. Water balanced across tower pans and basins.

11. Airflow across the tower within design rating according to fan curves.

12. Notes.

N. The following boiler and domestic water heater data is required:

1. Performance test results for rated capacity.

2. Boiler identification number.

3. Nameplate data; manufacturer, model, and serial number.

4. Water temperature entering/leaving the boiler.

5. Outside conditions: temperature, humidity, general cloud cover.

6. Barometric pressure.

O. The following air-cooled split system condensing unit data is required:

1. Performance test results for rated capacity.

2. Unit identification number.

3. Nameplate data, manufacturer, model, and serial number.

4. Compressor nameplate and actual amps, volts, phase, and hertz.

5. RPM of motors, where applicable.

6. Refrigerant type.

7. Suction/Discharge pressure when gage installed.

8. Number of stages.

9. Low-pressure/High-pressure control setting.

10. Condenser fan sequence stages.

11. Crankcase heater watts (nameplate).

12. Hot gas bypass installed - yes/no.

13. SCFM Air Flow Measurement vs. Design CFM.

P. The following air-cooled split system heat pump data is required:

1. Performance test results for rated heating and cooling capacities.

2. Unit identification number.

3. Nameplate data, manufacturer, model, and serial number.

4. Compressor nameplate and actual amps, volts, phase, and hertz.

5. RPM of motors, where applicable.

6. Refrigerant type.

7. Suction/Discharge pressure for both heating and cooling modes when gage installed.

8. Number of stages.

9. Low-pressure/High-pressure control setting.

10. Condenser fan sequence stages.

11. Crankcase heater watts (nameplate).

12. Hot gas bypass installed - yes/no.

13. SCFM Air Flow Measurement vs. Design CFM.

Q. The following sound test data is required:

1. Area or location.

2. Sound level in dB(A) as specified in Article 3.19.

3. Sound level at the center band frequencies of eight non-weighted octaves with equipment on and off for 5 rooms selected by the OAR/PROJECT INSPECTOR.

4. Plot of corrected sound-level reading on Noise Criteria (NC) curve for the measurements in Q 3 above.

R. The following vibration test data is required:

1. Equipment identification number.

2. Vibration levels at all accessible bearings, motors, fans, pumps, casings, and isolators.

3. Measurements in mils deflection and velocity in inches per second.

4. Each measurement taken in horizontal, vertical, and axial planes as accessible.

S. The following mixing damper leakage test data is required:

1. Equipment identification number (unit, box, zone, etc.).

2. Dry bulb temperature in the cold/hot (or bypass) deck.

3. Dry bulb temperature in the mixed air stream.

4. Calculated percent leakage.

5. Data above taken in the full cool and full heat (or bypass) mode.

6. Notes.

T. The following airflow station data is required:

1. Station identification number.

2. Nameplate data including effective area.

3. Differential test pressure or velocity.

4. Calculated CFM.

5. Actual CFM (from Pitot-tube traverse form).

6. Read out CFM.

7. Notes

U. The following unit heater data is required:

1. Equipment identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Test CFM (use manufacturer rated CFM if not ducted).

4. Heat test data per applicable procedure (hot water, electric, etc.).

5. Notes.

V. The following fan coil and unit ventilator data is required:

1. Equipment identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Tested supply CFM or manufacturer rated CFM if not ducted.

4. Tested outside air in CFM.

5. Motor data and actual amps and volts.

6. Cooling/Heating test data.

7. Static pressure.

8. Notes.

W. The following kitchen hood data is required:

1. Hood identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Pitot-tube traverse total air flow.

4. Exhaust and supply (when part of hood) CFM.

5. Exhaust and supply (when part of hood) test velocities shown on hood face diagram.

6. Face velocities.

7. Hood opening dimensions.

8. Notes (turbulence and flow patterns at the face and inside the hood).

X. The following laboratory hood data is required:

1. Hood identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Pitot-tube traverse total air flow.

4. Exhaust and supply (when part of hood) CFM.

5. Exhaust and supply (when part of hood) test velocities shown on hood face diagram.

6. Face velocities.

7. Hood opening dimensions.

8. Notes (turbulence and flow patterns at the face and inside the hood).

Y. The following data for water-to-water heat exchangers for domestic and/or heating is required:

1. Exchanger identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. GPM and Pressure drop through each side.

4. Capacity of each side.

5. Notes.

Z. The following pump data, including but not limited to, chilled water, heating hot water, cooling tower water, boiler feed, domestic hot water booster, domestic hot water circulation, sewage ejectors, sump pumps and domestic hot water booster is required:

1. Pump number.

2. Nameplate data; manufacturer, model, and serial number.

3. Motor data including nameplate data, actual amps, volts, RPM, horsepower, starter heater size, and capacity.

4. Pump discharge and suction pressure along with total dynamic head in the following modes.

5. Shut-off head FT, Wide open Head FT, and Final operating Head FT.

6. Final GPM Test plotted on a pump curve.

7. Notes.

AA. The following water flow station data is required:

1. Station identification number.

2. Nameplate data; manufacturer, model, and serial number.

3. Design and actual GPM.

4. Differential test pressure.

5. Setting (open turns, degree, etc.) if required GPM.

6. Notes.

BB. The following terminal box data is required:

1. Box identification number.

2. Node, address, or designation on system.

3. Box size.

4. Cooling CFM.

5. Minimum CFM (if applicable).

6. Heating CFM (if applicable).

7. Box fan amps and volts (if applicable).

8. For DDC controlled boxes, record computer readout maximum, minimum, and heat, along with box correction factor for calibrating to true CFM.

9. Notes.

**3.07 PROCEDURES**

A. Schedule the Work of this Section to test and balance activities to be completed prior to the date of Substantial Completion. CONTRACTOR shall place all heating, ventilating, and air conditioning equipment into operation during each day and until all HVAC adjusting, balancing, testing, demonstrations, and instructions on systems are completed. Agency shall prepare and submit reports within ten (10) days from completion of the Work of this Section to allow sufficient time for corrective measures to be completed before Substantial Completion of the Work. When an individual building or portion thereof is ready for occupancy, all equipment relative to such portion of Work shall be put into service, tested, and balanced.

B. Prior to the date of Substantial Completion, and upon completion of test and balance Work, place all exhaust fans in operation, force all air handling units, and air conditioning units into a 100 percent outdoor air economizer mode with heating and cooling locked out and flush the building continuously for a period of fourteen (14) days.

C. Coordinate test and balance procedures with any phased Project requirements so test and balance procedures on each phased portion of the Work will be completed prior to completion of said designated phase.

**3.08 FIELD EXAMINATION**

A. Before the commencement of test and balance Work, CONTRACTOR shall ascertain that following conditions are fulfilled:

1. Ensure that all water heating and water-cooling systems have been flushed, cleaned, and filled and high points vented.

2. Boilers (steam and hot water) are filled.

3. Refrigerant systems are fully charged with specified refrigerant.

4. Over-voltage and current protection have been provided for motors.

5. Equipment has been labeled as required.

6. Curves and descriptive data on each piece of equipment to be tested and adjusted are available as required.

7. Operations and maintenance manuals have been supplied.

8. Controls manufacturer and boiler-burner representatives shall be available for consultation and supervision of adjustments during tests.

9. Verify that heating and cooling coil fins are cleaned, combed and air filters clean, and installed.

10. Verify that duct systems are clean of debris and leakage is minimized, access doors are closed, and duct end caps are in place, and fire and volume dampers are in place and open.

11. Automatic control systems are completed and operating.

12. Start up and initial commissioning of all HVAC equipment except fans shall be by the manufacturer.

B. In addition to the above, CONTRACTOR shall establish a specific, coordinated plan which details how each area of existing building will be balanced during the various phases of the Work. The evaluation shall address, at a minimum, the following concerns:

1. OWNER operations.

2. Building safety and security policies. Prior to any fire safety or security systems shutdown at any time during the Work, CONTRACTOR shall first advise and coordinate with OWNER to ensure all concerned parties are notified.

3. Protecting furniture, computers, photocopiers, and other office equipment.

4. Protecting classroom fixtures and equipment.

5. Concerns specific and unique to building related issues.

6. Downtime required for each Air Handling Unit including projected time to return each portion of the building back to its normal occupancy temperature and humidity.

7. Shutdown and reactivation of the fire alarm system to avoid accidental alarms during test and balance and related Work.

**3.09 TEST AND BALANCE**

A. For each heating, ventilating, or air conditioning system the following shall be performed, recorded, and submitted in an approved format for review. Make, type, and model of unit, and location of each piece of equipment shall be included in the report. Readings shall include but not be limited to following:

1. Air Systems:

a. General

1) Verify all ductwork, dampers, grilles, registers, and diffusers have been installed per design and set in the full open position. Agency shall perform the following TAB procedures in accordance with AABC or NEBB National Standards. Where the requirements of the two standards are different, the more stringent requirements shall prevail. Also, if the Contract Documents impose a more stringent standard, then the Contract Documents shall prevail.

b. Zone, Branch, and Main Ducts:

1) Adjust ducts to within design CFM requirements by means of Pitot-tube duct traverse.

c. Supply Fans:

1) Fan Speeds: Test and adjust fan RPM to achieve maximum or design CFM. CONTRACTOR shall provide new belt pulleys when required.

2) Current and Voltage: Test and record motor voltage and amperage and compare data with the nameplate limits. Ensure fan motor is not in or above the service factor as published by the motor manufacturer.

3) Pitot-Tube Traverse: Perform a Pitot-tube traverse of main supply and return ducts, record total CFM.

4) Outside Air: Test and adjust the outside air using Pitot-tube traverse.

5) Static Pressure: Test and record system static profile of each supply fan.

6) Current and Voltage: Test and record motor voltage and amperage and compare data with the nameplate limits. Ensure fan motor is not in or above the service factor as published by the motor manufacturer.

d. Return, Relief, and Exhaust Fans:

1) Fan Speeds: Test and adjust fan RPM to achieve maximum or design CFM. CONTRACTOR shall provide new belt pulleys where required.

2) Pitot-Tube Traverse: Perform a Pitot-tube traverse of the main return ducts to obtain total CFM.

3. Static Pressure: Test and record system static profile of each fan.

e. VAV Systems:

1) Set volume regulators on all terminal boxes to meet design maximum and minimum CFM requirements.

2) Identification: Identify the type, location, and size of each terminal box. This information shall be recorded on terminal box data sheets.

f. Diffusers, Registers and Grilles:

1) Tolerances: Test and balance each diffuser, grille, and register to within 5 percent of design requirements.

2) Identification: Identify the type, location, and size of each grille, diffuser, and register. This information shall be recorded on air outlet data sheets.

g. Coils: Air Temperature: Once airflow is set to acceptable limits, agency shall take wet bulb and dry bulb air temperatures on the entering and leaving side of each cooling coil. Dry-bulb temperature shall be taken on the entering and leaving side of each heating coil.

h. Duct Leakage Testing:

1) On existing ductwork, agency shall calculate duct leakage by traversing the unit and reading associated diffusers.

2) On new installations each and every section of the entire air distribution system (all supply, return, exhaust, and relief ductwork) shall be tested at 1.5 times design static pressure. All ducts shall demonstrate 5 percent leakage maximum (per CBC).

i. Air Handling Units:

1) Prepare pressure profile and show design and actual CFM (outside air, return air, and supply air).

2) Measure and record each mode (minimum OA and 100 percent OA) where economizer cycle is specified.

3) Record pressure drops of all components (coils, filters, sound attenuators, louvers, dampers, and fans) and compare with design values.

4) Pressure profile and component pressure drops are performance indicators and are not to be used for flow measurements.

j. System Pressure Profiles:

1) Prepare pressure profiles from fan (supply, return, and exhaust) or air handling unit to extremities of system.

2) As a minimum, show pressure at each floor, main branch, and airflow measuring device.

3) Make pitot-tube traverses of all trunk lines and major branch lines where required for analysis of distribution system. Airflow measuring devices installed in ductwork, if available, may be utilized.

4) Record residual pressures at inlets of volume-controlled terminals at ends of system.

5) Show actual pressures at all static pressure control points utilized for constant or variable flow systems.

k. Fan speed adjustments and balancing for optimum acoustical performance:

1) As the very first step, the speed of all fans (supply, return, and exhaust inside packaged equipment or air handling units) shall be adjusted to deliver the required fan total air quantity with all volume dampers and other flow rate control devices fully open. Adjustments shall be made with the outdoor air intake dampers, return air dampers, and relief air dampers in the minimum outdoor air position. The adjustments shall be made again in the 100 percent outdoor air position in systems with 100 percent outdoor air economizers.

2) The above adjustment shall be done with wet cooling coils, where cooling coils are provided.

3) The airflow rates at each branch duct shall be adjusted as the second step with air with all volume dampers and other flow rate control devices fully open.

4) The airflow rates at each air inlet and outlet shall be adjusted as the final step. The volume damper in the branch duct shall be used for balancing. Opposed blade dampers at air inlets and outlets where provided shall only be used for fine adjustments and shall not be closed beyond 60 percent open or when the dampers start to generate audible noise.

5) CONTRACTOR shall provide the labor and materials for all dampers, pulleys, and belt changes required for balancing. The design documents indicate the worst-case scenario with safety factors in fan static pressures for contingency. Properly coordinated and installed air systems may require a lower static pressure and a reduction in fan speed.

2. Water Systems: CONTRACTOR shall confirm all equipment, piping, and coils have been filled and purged, strainers are clean, and all balancing valves (except bypass valves) are set full open. Agency shall perform the following TAB procedures in accordance with the AABC, TABB, or NEBB National Standards:

B. Pumps:

1. Test and adjust chilled water, hot water, and condenser water pumps to achieve maximum or design GPM.

2. Measure and record suction and discharge pressures.

3. Check pumps for proper operation. Pumps shall be free of vibration and cavitation.

4. Current and Voltage: Agency shall test and record motor voltage and amperage and compare data with the nameplate limits. Ensure pump motor is not in or above the service factor as published by the motor manufacturer.

5. Adjust pump flow by adjusting and setting balancing valves to obtain amperage reading on a clamp-on ammeter that corresponds to amperage indicated on pump's curves for required flow.

6. Verify that the motor is not drawing more current than indicated on motor plate rating. When actual flows of primary pumps are found by test to vary more than 5 percent from specified amount, system shall be re-balanced to regulate flow within this tolerance. When a flow indicating device(s) is in circuit, it shall be used to verify pump flows.

7. When testing is completed, a pump capacity chart with pump number and location indicated shall be marked indicating operating point of pump on the curve. Chart shall then be included in the report.

C. Cooling Towers:

1. Test and balance water flows, balance tower cells, and flows between towers.

2. Test and record temperature profiles for water and airside operation.

3. Outside Climatic Conditions: Outside air dry bulb (DB) temperature, wet bulb (WB) temperature, and atmospheric conditions, during temperature profile runs.

D. Chillers: (Start-up and initial commissioning by manufacturer only.)

1. Test and balance chiller water flows to achieve maximum or design GPM.

2. Current and Voltage: Test and record motor voltage and amperage and compare data with the nameplate limits. Ensure compressor motor is not in or above the service factor as published by the motor manufacturer.

3. Test and record temperature and pressure profiles of chillers.

a. Inlet and outlet water temperature.

b. Inlet and outlet water pressure.

c. Evaporator temperature.

d. Condensing temperature pressure.

e. Purge pressure.

f. Oil temperature and pressure.

4. Outside Climatic Conditions: Outside air DB temperature, WB temperature, and atmospheric conditions, during temperature profile runs.

E. Boilers: (Start-up and initial commissioning by manufacturer only.) Test and balance boilers only after test and balance of pumps have been completed. Boilers shall not be initially operated, or tests performed with students or faculty on the Project site. Boilers shall be tested for the following:

1. Heating Hot Water Boilers and Domestic Hot Water Boilers:

a. Current and Voltage: Test and record motor voltage and amperage and compare data with the nameplate limits. Ensure motor is not in or above the service factor.

b. Test and balance water flow through water boilers.

c. Test and record temperature and pressure profiles of water and/or steam boilers.

d. Upon completion of tests, controls and devices shall be returned to their normal operating condition and boiler shall remain in service.

2. Steam Boilers: Start-up and initial commissioning by manufacturer only.

F. Heat Exchangers:

1. Steam to Hot Water Heat Exchanger: Steam pressure, entering and leaving hot water temperatures, gpm flow, pressure drop, and control set point.

2. Water to Water Heat Exchanger:

a. Primary Heating Water: Entering and leaving hot water temperatures, gpm flow, and pressure drop.

b. Secondary Heated Water: Entering and leaving hot water temperatures, gpm flow, pressure drop, and control set point.

G. Coils:

1. Tolerances: Test and balance all chilled-water and hot-water coils within 5 percent of design requirements.

2. Verify the type, location, final pressure drop, and GPM of each coil.

H. System Mains and Branches including chilled water, heating hot water, cooling tower water, domestic hot water and domestic cold water:

1. Balance water flow in pipes to achieve maximum or design GPM.

I. Steam Heating Systems:

1. Heating Coils: Steam pressure at coils, cfm, coil pressure drop, entering and leaving air dry bulb temperatures.

2. Boilers:

a. Steam pressure, temperature, and quantity of feed-water (see Testing and Adjusting procedures).

b. Make, type, serial number, and rated capacity.

c. Flue gas temperature at boiler outlet ahead of back-draft diverter.

d. Percent carbon dioxide in flue gas.

e. Condensate quantities and temperatures.

3. Air Conditioning Units: (Start-up and initial commissioning by manufacturer only.)

a. Suction pressure and temperature.

b. Discharge pressure and temperature.

c. Amps and volts.

d. Make, type, and model of unit, capacity rating.

e. Ambient temperature: WB, DB.

f. Supply, return, relief, and exhaust fans shall be balanced as indicated in Section 3.09, A, 1, Air Systems.

g. Proper operation of controls: Temperature controllers and safety devices shall be tested during operating tests, with all other controls and devices, except one under test, being by-passed.

h. Upon completion of tests, controls and devices shall be returned to their normal operating condition and boiler shall remain in service.

4. Condensing and Refrigerating Units: (Start-up and initial commissioning by manufacturer only.)

a. Suction pressure and temperature.

b. Discharge pressure and temperature.

c. Amps and volts.

d. Make, type, and model of unit, capacity rating.

e. Ambient temperature: WB, DB.

f. Proper operation of controls: Temperature controllers and safety devices shall be tested during operating tests, with all other controls and devices, except one under test, being by-passed.

g. Upon completion of tests, controls and devices shall be returned to their normal operating condition and boiler shall remain in service.

5. Split System Heat Pump Units: (Start-up and initial commissioning by manufacturer only.)

a. Suction pressure and temperature.

b. Discharge pressure and temperature.

c. Amps and volts.

d. Make, type, and model of unit, capacity rating.

e. Ambient temperature: WB, DB.

f. Supply, return, relief, and exhaust fans shall be balanced as indicated in Sub-paragraph 3.09.A.1, Air Systems.

g. Proper operation of controls: Temperature controllers and safety devices shall be tested during operating tests, with all other controls and devices, (except one under test) being by-passed.

h. Upon completion of tests, controls and devices shall be returned to their normal operating condition and boiler shall remain in service.

6. MISCELLANEOUS:

a. Electric Heaters:

1. Amperage.
2. Voltage.
3. Make, type, model, and name plate capacity rating.

**3.10 VERIFICATION OF HVAC CONTROLS**

A. Agency shall verify in conjunction with CONTRACTOR all control components are installed in accordance with the intent of the Contract Documents and are functioning according to the design intent, including all electrical interlocks, damper sequences, air and water resets, fire stats, and other safety devices.

B. CONTRACTOR shall verify all control components are calibrated and set for design operating conditions and intent.

**3.11 TEMPERATURE TESTING**

A. To verify system control and operation, agency shall perform a series of three temperature tests taken at approximately two-hour intervals in each separately controlled zone. The resulting temperatures shall not vary more than two degrees Fahrenheit from the thermostat or control set point during the tests. Outside temperature and humidity shall also be recorded during the testing periods.

**3.12 KITCHEN HOOD TESTING**

A. Agency shall test and adjust hood total airflow by duct Pitot-tube traverse. If a Pitot-tube traverse is not practical, an explanation of why a traverse was not made must be made in writing to Architect and subsequently appear on the appropriate data sheet. Face velocities shall be tested under design operating conditions using a maximum of a one square foot grid pattern across the entire open face. CONTRACTOR shall set sash height on hoods to obtain face velocities within 20 percent of 100 feet per minute unless specified otherwise. Agency shall test and adjust exhaust airflows and make-up air flows to maintain design hood pressures and face velocities and design room pressurization. Agency shall test for turbulence and proper air flow patterns at the face and inside the hoods using a hand-held smoke puffer or other approved smoke-emitting device.

**3.13 FUME HOOD TESTING**

A. Agency shall test and adjust fume hood total airflow by duct Pitot-tube traverse. If a Pitot-tube traverse is not practical, an explanation of why a traverse was not made must be made in writing to Architect and subsequently appear on the appropriate data sheet. Face velocities shall be tested under design operating conditions using a maximum of a one square foot grid pattern across the entire open face. CONTRACTOR shall set sash height on hoods to obtain face velocities within 20 percent of 100 feet per minute unless specified otherwise. Agency shall test and adjust VAV controllers to obtain design exhaust airflows and make-up air flows to maintain design hood pressures and face velocities and design room pressurization. Agency shall test for turbulence and proper air flow patterns at the face and inside the hoods using a hand-held smoke puffer or other approved smoke-emitting device.

**3.14 BUILDING/ZONE PRESSURIZATION**

A. Agency shall test and adjust building/zone pressurization by setting the design flows to meet the required flow direction and pressure differentials. Positive/Negative area(s) supply air shall be set to design flow and exhaust air rates adjusted to obtain the required pressure differential(s).

**3.15 FIRE AND SMOKE DAMPER TESTING**

A. This work is to be performed by OWNER and State Fire Marshall. Do not include in agency scope of work.

**3.16 LIFE SAFETY CONTROLS TESTING**

A. This work is to be performed by OWNER and State Fire Marshall. Do not include in agency scope of Work.

**3.17 FINAL TABULATION**

A. After heating, ventilating, and air conditioning components are satisfactorily tested and balanced, entire system shall be put into operation and all pressures, temperatures, gpm, cfm, velocities, etc., shall be recorded and checked against design schedules. Design requirements shall be listed on reports and final tabulation shall be within a tolerance of plus or minus five percent of design requirements.

B. Readings at various locations as described herein will be made every hour for four (4) hours, during normal working hours for three (3) days. Boilers, forced air furnaces, and chillers shall be started up far enough in advance to meet design conditions during period of testing.

**3.18 VIBRATION TESTING**

A. Furnish instruments and perform vibration measurements if specified in Division 23. Provide measurements for all rotating HVAC equipment half horsepower and larger, including reciprocating/centrifugal/screw/scroll compressors, pumps, fans, and motors.

B. Record initial and final measurements for each unit of equipment on test forms. Where vibration readings exceed allowable tolerance and efforts to make corrections have proved unsuccessful, forward a separate report to ARCHITECT.

**3.19 SOUND TESTING**

A. Perform and record sound measurements as specified in this Section and in Section 23 0548: HVAC Sound, Vibration and Seismic Control. Take additional readings if required by ARCHITECT.

B. Measuring equipment and methods shall comply with the current requirements of the AABC, NEBB, TABB, and ANSI S12.60. Take measurements with a calibrated Type 1 sound level meter and octave band analyzer.

C. Sound reference levels, formulae, and coefficients shall be according to ASHRAE Handbook: HVAC Applications, Chapter on Sound and Vibration Control.

D. Where sound pressure levels are specified as noise criteria or room criteria in Section 23 0548: HVAC Sound, Vibration and Seismic Control determine compliance with the Contract Documents as follows:

1. Reduce background noise as much as possible by shutting off unrelated audible equipment.

2. Measure octave band sound pressure levels with specified equipment "off".

3. Measure octave band sound pressure levels with specified equipment "on".

4. Use difference in corresponding readings to determine sound pressure due to equipment. Sound pressure level, due to equipment equals sound pressure level with equipment "on" minus factor.

DIFF.: 0 1 2 3 4 5 9-10 or More

FACTOR: 10 7 4 3 2 1 0

5. Plot octave bands of sound pressure level due to equipment for typical rooms, on a graph, which also shows, noise criteria (NC) curves.

E. Where sound levels are required in dbA, measure sound levels using the A-frequency-weighting of meter. Single value readings will be used instead of octave band analysis.

F. Measure sound levels at each octave band as NC or RC (room criteria) if indicated in the Drawings or other Spec Sections. Where measured sound levels exceed specified level, CONTRACTOR shall take all remedial action and necessary sound tests shall be repeated. Sound tests after remedial action shall be in octave band in NC or RC for the room and also at each diffuser, grille, or register in occupied areas. Sound levels shall be measured approximately five feet above floor on a line approximately 45 degrees to center of opening, on the A- and C-frequency-weighting of the measuring instrument.

G. Measure and record sound levels in decibels for each room per current ANSI S12.60.

H. Report shall include ambient sound levels, taken without air-handling equipment operating, of rooms in which above openings are located. A report shall also be made of any noise caused by mechanical vibration.

# END OF SECTION