SECTION 15950
TESTING, ADJUSTING, AND BALANCING

PART 1 - GENERAL

1.01 PROVISIONS INCLUDED

A. The general provisions of the Contract, including General and Supplementary General Conditions, and Division 1 General Requirements, apply to work specified in this Section.

B. Comply with Section 15050.

1.02 SUMMARY

A. This Section includes testing, adjusting, and balancing HVAC systems to produce design objectives, including the following:
1. Balancing airflow and water flow within distribution systems, including submains, branches, and terminals, to indicated quantities according to specified tolerances.
2. Adjusting total HVAC systems to provide indicated quantities, including replacement of sheaves and pulleys to achieve desired flow rate.
3. Measuring electrical performance of HVAC equipment.
4. Setting quantitative performance of HVAC equipment.
5. Verifying that automatic control devices are functioning properly.
6. Measuring sound and vibration.
7. Reporting results of the activities and procedures specified in this Section.
8. Testing of performance of fume hoods in accordance with ASHRAE Standard 110-1995.

B. Test, adjust and balance the following mechanical systems:
1. Supply air systems, all pressure ranges; including variable volume systems.
2. Return air systems.
3. Exhaust air systems.
4. Hydronic systems (CW, HW, ER).
5. Fume Hoods
6. Verify temperature control system operation.

1.03 DEFINITIONS

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

B. Balance: To proportion flows within the distribution system, including submains, branches, and terminals, according to design quantities.

C. 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by one or more factors of high air velocity, low ambient temperature, or direction of airflow, whereby more heat is withdrawn from a person’s skin than is normally dissipated.

D. Procedure: An approach to and execution of a sequence of work operations to yield repeatable results.

E. Report Forms: Test data sheets for recording test data in logical order.

F. 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.

G. Suction Head: The height of fluid surface above the centerline of the pump on the suction side.

H. System Effect: A phenomenon that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system.

I. 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.

J. Terminal: A point where the controlled medium, such as fluid or energy, enters or leaves the distribution system.

K. Test: A procedure to determine quantitative performance of a system or equipment.

L. Testing, Adjusting, and Balancing Agent: The entity responsible for performing and reporting the testing, adjusting, and balancing procedures.

M. AABC: Associated Air Balance Council.

N. AMCA: Air Movement and Control Association.

O. NEBB: National Environmental Balancing Bureau.

P. SMACNA: Sheet Metal and Air Conditioning Contractors' National Association.

1.04 SUBMITTALS

A. Quality-Assurance Submittals: With the General Contractor's initial application for payment, as specified in Section 01290, "Payment Procedures", submit 2 copies of evidence that testing, adjusting, and balancing Agent and this Project's testing, adjusting, and balancing team members meet the qualifications specified in the "Quality Assurance" Article below.

B. Contract Documents Examination Report: Within 45 days from the Contractor's Notice to Proceed, submit 2 copies of Contract Documents examination report as specified in Part 3 of this Section.

C. Strategies and Procedures Plan: Within 60 days from the Contractor's Notice to Proceed, submit 2 copies of the testing, adjusting, and balancing strategies and step-by-step procedures as specified in Part 3 "Preparation" Article below. Include a complete set of report forms intended for use on this Project.

D. Certified Testing, Adjusting, and Balancing Reports: Submit 2 copies of reports prepared, as specified in this Section, on approved forms certified by the testing, adjusting, and balancing Agent.

E. Warranty: Submit 2 copies of special warranty specified in the "Warranty" Article below.

1.05 QUALITY ASSURANCE

A. Agent Qualifications: Engage a testing, adjusting, and balancing agent certified by either AABC or NEBB.

B. Testing, Adjusting, and Balancing Conference: Meet with Owner's and Architect's representatives on approval of testing, adjusting, and balancing strategies and procedures plan to develop a mutual understanding of the details. Ensure participation of testing, adjusting, and balancing team members, equipment manufacturers' authorized service representatives, HVAC controls Installer, and other support personnel. Provide 7 days advance notice of scheduled meeting time and location.

1. Agenda Items: Include at least the following:
   a. Submittal distribution requirements.
   b. Contract Documents examination report.
   c. Testing, adjusting, and balancing plan.
   d. Laboratory fume hood performance testing plan.
   e. Work schedule and Project site access requirements.
   f. Coordination and cooperation of trades and subcontractors.
   g. Coordination of documentation and communication flow.

C. Certification of Testing, Adjusting, and Balancing Reports: Certify the testing, adjusting, and balancing field data reports. This certification includes the following:

1. Review field data reports to validate accuracy of data and to prepare certified testing, adjusting, and balancing reports.
2. Certify that testing, adjusting, and balancing team complied with approved testing, adjusting, and balancing plan and procedures specified and referenced in this Specification.

D. Testing, Adjusting and Balancing Reports: Use standard forms from AABC’s "National Standards for Testing, Adjusting, and Balancing", or from NEBB's "Procedural Standards for Testing, Adjusting and Balancing of Environmental Systems".

E. Instrumentation Type, Quantity, and Accuracy: As described in AABC national standards, as described in NEBB’s "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems," Section II, "Required Instrumentation for NEBB Certification."

1. When testing fume hoods, in addition comply with the American Society of Heating, Refrigeration and Air–Conditioning Engineers (ASHRAE) 110-1995 "Method of Testing Performance of Laboratory Fume Hoods."

F. Instrumentation Calibration: Calibrate instruments at least every 6 months or more frequently if required by instrument manufacturer.

G. Comply with USM IDAT per section 01810.

1.06 PROJECT CONDITIONS

A. Systems Operation: Systems shall be fully operational prior to beginning procedures.

B. Partial Owner Occupancy: The Owner may occupy completed areas of building before Substantial Completion. Cooperate with Owner during testing, adjusting, and balancing operations to minimize conflicts with Owner's operations.

1.07 COORDINATION

A. Coordinate efforts of factory-authorized service representatives for systems and equipment, HVAC controls installers, and other mechanics to operate HVAC systems and equipment to support and assist testing, adjusting, and balancing activities.

B. Notice: Provide 7 days' advance notice for each test. Include scheduled test dates and times.

C. Perform testing, adjusting, and balancing after leakage and pressure tests on air and water distribution systems have been satisfactorily completed.

D. Coordinate with Universities safety officer for laboratory fume hood performance testing. SMMA Mechanical Engineer and Universities safety officer shall witness the tests.

1.08 WARRANTY

A. General Warranty: The national project performance guarantee specified in this Article shall not deprive the Owner of other rights the Owner may have under other provisions of the Contract Documents and shall be in addition to, and run concurrent with, other warranties made by the Contractor under requirements of the Contract Documents.

B. Provide a guarantee on AABC'S "National Standards" forms, or on NEBB forms, stating that AABC or NEBB, respectively, will assist in completing the requirements of the Contract Documents if the testing, adjusting, and balancing Agent fails to comply with Contract Documents. Guarantee includes the following provisions:
   1. The certified Agent has tested and balanced systems according to the Contract Documents.
   2. Systems are balanced to optimum performance capabilities within design and installation limits.

PART 2 - PRODUCTS Not Used.

PART 3 - EXECUTION

3.01 EXAMINATION

A. Examine the Contract Documents to become familiar with project requirements and to discover conditions in system designs that may preclude proper testing, adjusting, and balancing of systems and equipment.

   1. Verify balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are required by Contract Documents. Verify quantities and locations of balancing devices are accessible and appropriate for effective balancing and for efficient system and equipment operation.

B. Examine approved submittal data of HVAC systems and equipment.

C. Examine project record documents described in Section 01770 "Closeout Procedures."

D. Examine equipment performance data, including fan and pump curves. Relate performance data to project conditions and requirements, including system effects that can create undesired or unpredicted conditions that cause reduced capacities in all or part of a system. Calculate system effect factors to reduce performance ratings of HVAC equipment when installed under conditions different from those presented when equipment was performance tested at factory. To calculate system effects for air systems, use tables and charts found in AMCA 201, "Fans and Systems," Sections 7 through 10; or in SMACNA's "HVAC Systems--Duct Design," Sections 5 and 6. Compare this data with design data and installed conditions.

E. Examine system and equipment installations to verify they are complete and that testing, cleaning, adjusting, and start-up specified in individual Specification Sections have been performed.

F. Examine system and equipment test reports.

G. Examine HVAC system and equipment installations to verify indicated balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers, are properly installed, and their locations are accessible and appropriate for effective balancing and for efficient system and equipment operation.

H. Examine systems for functional deficiencies that cannot be corrected by adjusting and balancing.

I. Examine air-handling equipment to ensure clean filters have been installed, 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 mixing boxes, to verify they are accessible and their controls are connected and functioning.

K. Examine plenum ceilings, utilized for supply air, to verify they are airtight. Verify pipe penetrations and other holes are sealed.

L. Examine strainers for clean screens and proper perforations.

M. Examine 2-way valves for proper installation for their intended function of diverting fluid flows.

N. Examine 3-way valves for proper installation for their intended function of diverting or mixing fluid flows.

O. Examine heat-transfer coils for correct piping connections and for clean and straight fins.

P. Examine equipment for installation and for properly operating safety interlocks and controls.

Q. Examine automatic temperature system components to verify the following:
   1. Dampers, valves, and other controlled devices operate by intended controller.
   2. Dampers and valves are in position indicated by controller.

3. Integrity of valves and dampers for free and full operation and for tightness of fully closed and fully open positions. This includes dampers in multizone units, mixing boxes, and variable-air-volume terminals.
4. Automatic modulating and shutoff valves, including 2-way valves and diverting valves, are properly connected.
5. Thermostats are located to avoid adverse effects of sunlight, drafts, and cold walls.
6. Sensors are located to sense only the intended conditions.
7. Sequence of operation for control modes is according to the Contract Documents.
8. Controller set points are set at design values. Observe and record system reactions to changes in conditions. Record default set points if different from design values.
9. Interlocked systems are operating.
10. Changeover from heating to cooling mode occurs according to design values.

R. Report deficiencies discovered before and during performance of testing, adjusting, and balancing procedures.

3.02 PREPARATION

A. Prepare a testing, adjusting, and balancing plan that includes strategies and step-by-step procedures.

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

3.03 GENERAL TESTING AND BALANCING PROCEDURES

A. Perform testing and balancing procedures on each system according to the procedures contained in AABC national standards, or in NEBB's "Procedural Standards for Testing, Adjusting, and Balancing of Environmental Systems" and this Section.

B. Cut insulation, ducts, pipes, and equipment cabinets for installation of test probes to minimum extent necessary to allow adequate performance of procedures. After testing and balancing, close probe holes and patch insulation with new materials identical to those removed. Restore vapor barrier and finish according to insulation Specifications for this Project.

C. Mark equipment settings with paint or other suitable, permanent identification material, including damper-control positions, valve indicators, fan-speed-control levers, and similar controls and devices, to show final settings.

3.04 FUNDAMENTAL AIR SYSTEM BALANCING PROCEDURES

A. Prepare test reports for both fans and outlets. Obtain manufacturer's outlet factors and recommended testing procedures. Cross-check summation of required outlet volumes with required fan volumes.

B. Prepare schematic diagrams of systems "as-built" duct layouts.

C. For variable-air-volume systems, develop a plan to simulate diversity.

D. Determine best locations in main and branch ducts for accurate duct airflow measurements.

E. Check airflow patterns from outside-air louvers and dampers and return- and exhaust-air dampers, through supply-fan discharge and mixing dampers.

F. Locate start-stop and disconnect switches, electrical interlocks, and motor starters.

G. Verify 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.

3.06 VARIABLE-AIR-VOLUME SYSTEM ADDITIONAL PROCEDURES

A. Compensating for Diversity: When total airflow of all terminal units is more than fan design airflow volume, place a selected number of terminal units at a maximum set-point airflow condition until total airflow of terminal units equals design airflow of fan. Select reduced airflow terminal units so they are distributed evenly among branch ducts.

B. Pressure-Independent, Variable-Air-Volume Systems: After fan systems have been adjusted, adjust variable-air-volume systems as follows:

1. Set outside-air dampers at minimum, and return- and exhaust-air dampers at a position that simulates full-cooling load.
2. Select terminal unit that is most critical to supply-fan airflow and static pressure. Measure static pressure. Adjust system static pressure so entering static pressure for critical terminal unit is not less than sum of terminal unit manufacturer's recommended minimum inlet static pressure plus static pressure needed to overcome terminal-unit discharge duct losses.
3. Measure total system airflow. Adjust to within 10 percent of design airflow.
4. Set terminal units at maximum airflow and adjust controller or regulator to deliver designed maximum airflow. Use terminal unit manufacturer's written instructions to make this adjustment. When total airflow is correct, balance air outlets downstream from terminal units as described for constant-volume air systems.

5. Set terminal units at minimum airflow and adjust controller or regulator to deliver designed minimum airflow. Check air outlets for a proportional reduction in airflow as described for constant-volume air systems.
    a. If air outlets are out of balance at minimum airflow, report the condition but leave outlets balanced for maximum airflow.
6. Remeasure return airflow to fan while operating at maximum return airflow and minimum outside airflow. Adjust fan and balance return-air ducts and inlets as described for constant-volume air systems.
7. Measure static pressure at most critical terminal unit and adjust static-pressure controller at main supply-air sensing station to ensure adequate static pressure is maintained at most critical unit.
8. Record final fan performance data.

3.07 FUME HOOD TESTING

A. Prior to fume hood testing and certification, verify exhaust system operation and fume hood exhaust flow control valve installation and operation.

B. Test all hoods installed as part of this Contract.

C. Perform testing of exhaust air flow both in the exhaust branch serving the fume hood as well as in accordance with ASHRAE 110. Take measurements and data as specifed for “Fume Hood Test Reports” in Article 3.20, "Final Report," of this Specification.

D. Perform fume hood testing and certification of laboratory fume hoods in accordance with ASHRAE 110 –Methods of Testing Performance of Laboratory Fume Hoods with the modifications described in this Article.

E. Test and Measurement Equipment:

1. Anemometers:
    a. Accuracy: $\pm$ 5% of reading
    b. Internal Time Constant: <= 100 milliseconds

2. Tracer Gas Ejector shall be in accordance with ANSI/ASHRAE 110

3. Trace Gas Sensor:
    a. Sensitivity: 0.01 to 100 ppm
    b. Accuracy:
    c. Above 0.1 ppm: $\pm$ 10% of reading
    d. Below 0.1 ppm: $\pm$ 25% of reading

4. Data Acquisition System: Minimum 6 channel system capable of simultaneous sampling at 10 Hz or greater.

F. Tracer Gas Fume Hood Modified Test Procedure:

1. Test hood using simulated apparatus located with in the fume hood during test procedure. This apparatus shall consist of the following,
    a. Two 3.8 Liter round paint cans.

b. One 300 mm x 300 mm x 300 mm cardboard box.
c. Three 150 mm x 150 mm x 300 mm cardboard boxes.

2. Position the above items from 150 mm to 250 mm behind the sash, randomly distributed and supported off the work surface by 50 mm x 50 m blocks.

3. Test gas flow rate: 6 Liters per minute.

4. Test position of the tracer gas: Center of the mannequin

5. Acceptable test results will be 0.05 PPM of better.

6. Perform the standard tracer gas test described in ASHRAE 110. At the conclusion of each 5 minute test there perform three rapid walk-bys at 300 mm behind the test mannequin, spaced 30 seconds apart. If there is a rise in test gas concentration, it cannot exceed 0.10 ppm and must return to 0.05 ppm with in 15 seconds.

7. There shall be a minimum of three and a maximum of five people in the test room during the test procedure.

G. Face Velocity Modified Test Procedure: Conduct face velocity testing to determine flow rate and turbulence and the face of the hood. Testing parameters shall include:

1. Measured Face Velocity (FVm expressed in m/s): Face velocity measured in the plane of the sash at three locations at any point in time. Samples for each sensor shall be recorded simultaneously at no less than 10 Hz. The sensors shall basically be point sensors located in the middle of 1' by 1' grid sectors. Move the three sensors to other sectors for subsequent testing periods. Averages shall be calculated for any point in time to assess overall measured face velocity; however individual sensor samples shall be used in calculating TI for each sensor. These face velocity measurements shall be made with sash(es) open and closed. "Open" shall mean the sashes positioned to their maximum design position (to sash stop, typically 18" to 22"). "Closed" shall mean open to 6" for a vertical rising only sash and center panels open 6"' on the horizontally sliding panels with the vertically rising sash closed.

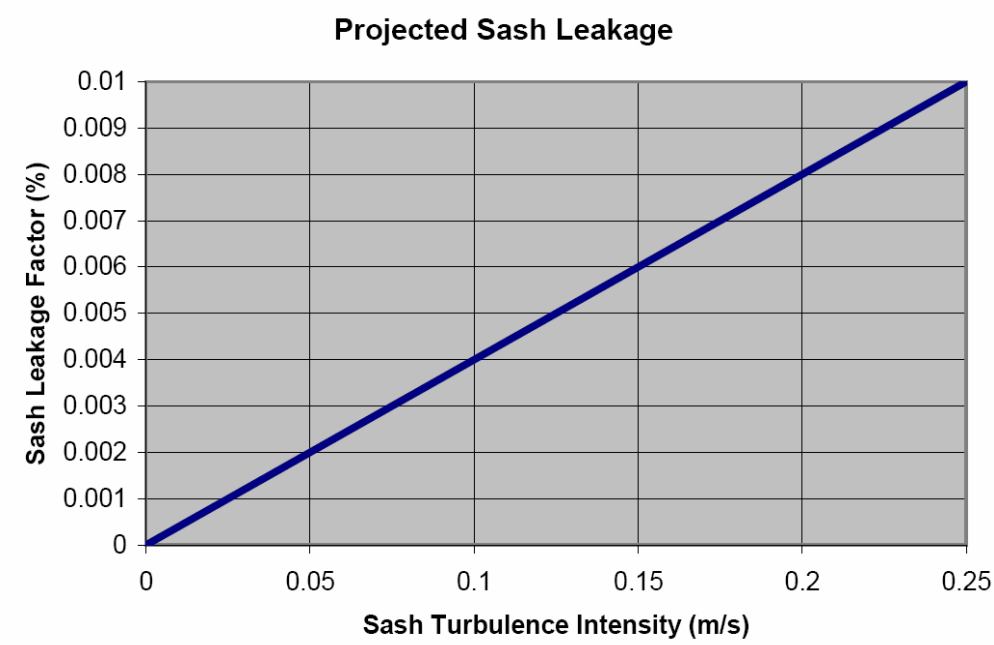
2. Steady State Face Velocity (SSFV): The average of all sampled face velocities for a 5 second period. Determine two SSFVs for both measured face velocity and calculated face velocity; one before the event (SSFVb) and one after (SSFVa). Start the SSFVa two seconds after the end of TSS. The second suffix m (for measured) or c (for calculated) indicates the type of assessment.

3. Turbulence Intensity (TI expressed in m/s): Calculated root mean square of the fluctuating face velocity determined using FVm, calculated as follows:

$$sqrt[Sum_{1\text{-}n}\{(FVm_1\text{-}SSFV)^2 + \ldots + (FVm_n\text{-}SSFV)^2\}/n]$$

Calculate this value for each of the steady state conditions preceding and following each event. Correlate to a "Box Leakage Factor" using the following graph of the installation using the "Methodology for Optimization of Laboratory Fume Hood Containment" (MOLHC) by NIH Office of the Director, Farhad Memarzadeh principle investigator.

While this value does not have a pass/fail requirement, it is the fundamental indicator of containment and therefore shall be clearly reported.



H. Retest and adjust systems until fume-hood performance complies with Contract Documents.

I Refer to Section 11610 for additional testing requirements.

3.08 FUNDAMENTAL PROCEDURES FOR HYDRONIC SYSTEMS

A. Prepare test reports with pertinent design data and number in sequence starting at pump to end of system. Check sum of branch-circuit flows against approved pump flow rate. Correct variations that exceed plus or minus 5 percent.

B. Prepare schematic diagrams of system "as-built" piping layouts.

C. Prepare hydronic systems for testing and balancing according to the following, in addition to general preparation procedures specified above:
1. Open all manual valves for maximum flow.
2. Check expansion tank liquid level.
3. Check makeup-water-station pressure gage for adequate pressure for highest vent.
4. Check flow-control valves for specified sequence of operation and set at design flow.
5. Set differential-pressure control valves at 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.

3.09 HYDRONIC SYSTEM BALANCING PROCEDURES

A. Determine water flow at pumps. Use the following procedures, except for positive-displacement pumps:

1. Verify impeller size by operating pump with discharge valve closed. Verify with pump manufacturer this will not damage pump. Read pressure differential across pump. Convert pressure to head and correct for differences in gage heights. Note point on the manufacturer's pump curve at zero flow and confirm pump has intended impeller size.

2. Check system resistance. With all valves open, read pressure differential across pump and mark pump manufacturer's head-capacity curve. Adjust pump discharge valve until design water flow is achieved.

3. Verify pump-motor brake horsepower. Calculate intended brake horsepower for system based on pump manufacturer's performance data. Compare calculated brake horsepower with nameplate data on pump motor. Report conditions where actual amperage exceeds motor nameplate amperage.

4. Report flow rates that are not within plus or minus 5 percent of design.

B. Set calibrated balancing valves, if installed, at calculated presettings.

C. Measure flow at all stations and adjust, where necessary, to obtain first balance.
1. System components that have Cv rating or an accurately cataloged flow-pressure-drop relationship may be used as a flow-indicating device.

D. Measure flow at main balancing station and set main balancing device to achieve flow that is 5 percent greater than design flow.

E. Adjust balancing stations to within specified tolerances of design flow rate as follows:
1. Determine balancing station with highest percentage over design flow.
2. Adjust each station in turn, beginning with station with highest percentage over design flow and proceeding to the station with the lowest percentage over design flow.
3. Record settings and mark balancing devices.

F. Measure pump flow rate and make final measurements of pump amperage, voltage, rpm, pump heads, and system pressures and temperatures, including outdoor-air temperature.

G. Measure differential-pressure control valve settings existing at conclusions of balancing.

3.10 VARIABLE-FLOW HYDRONIC SYSTEM ADDITIONAL PROCEDURES

A. Balance systems with automatic 2- and 3-way control valves by setting systems at maximum flow through heat-exchange terminals and proceed as specified above for hydronic systems.

3.11 MOTORS

A. Motors, 1/2 HP and Larger: Test at final balanced conditions and record the following data:
1. Manufacturer, model, and serial numbers.
2. Motor horsepower rating.

3. Motor rpm.
4. Efficiency rating if high-efficiency motor.
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 manual bypass for controller to prove proper operation. Record observations, including controller manufacturer, model and serial numbers, and nameplate data.

3.12 CHILLERS

A. Balance water flow through each evaporator and condenser to within specified tolerances of design 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. Condenser water entering and leaving temperatures, pressure drop, and water flow.
3. Evaporator and condenser refrigerant temperatures and pressures, using instruments furnished by the chiller manufacturer.
4. Power factor if factory-installed instrumentation is furnished for measuring kW.
5. The kW input if factory-installed instrumentation is furnished for measuring kW.
6. Capacity: Calculate in tons of cooling.
7. Air-Cooled Chillers: Verify condenser-fan rotation and record fan data, including number of fans and entering- and leaving-air temperatures.

3.13 CONDENSING UNITS

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

3.14 BOILERS

A. Measure entering- and leaving-water temperatures and water flow.

3.15 HEAT-TRANSFER COILS

A. Water Coils: Measure the following data for each coil:
1. Entering- and leaving-water temperatures.
2. Water flow rate.
3. Water pressure drop.
4. Dry-bulb temperatures of entering and leaving air.
5. Wet-bulb temperatures of entering and leaving air for cooling coils.
6. Airflow.
7. Air pressure drop.

3.16 TEMPERATURE TESTING

A. During testing, adjusting, and balancing, report need for adjustment in temperature regulation within the automatic temperature-control system.

B. Measure indoor wet- and dry-bulb temperatures every other hour for a period of 2 successive 8-hour days, in each separately controlled zone, to prove correctness of final temperature settings. Measure when the building or zone is occupied.

C. Measure outside-air, wet- and dry-bulb temperatures.

3.17 TEMPERATURE-CONTROL VERIFICATION

A. Verify controllers are calibrated and commissioned.

B. Check transmitter and controller locations and note conditions that would adversely affect control functions.

C. Record controller settings and note variances between set points and actual measurements.

D. Verify operation of limiting controllers (i.e., high- and low-temperature controllers).

E. Verify free travel and proper operation of control devices such as damper and valve operators.

F. Verify sequence of operation of control devices. Note air pressures and device positions and correlate with airflow and water-flow measurements. Note speed of response to input changes.

G. Confirm interaction of electrically operated switch transducers.

H. Confirm interaction of interlock and lockout systems.

I. Verify main control supply-air pressure and observe compressor and dryer operations.

J. Record voltages of power supply and controller output. Determine if the system operates on a grounded or nongrounded power supply.

K. Note operation of electric actuators using spring return for proper fail-safe operations.

3.18 TOLERANCES

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

3.19 REPORTING

A. Contract Documents Examination Report: Based on examination of the Contract Documents as specified in "Examination" Article above, prepare a report on the adequacy of design for system balancing devices. Recommend changes and additions to system balancing devices to

facilitate proper performance measuring and balancing. Recommend changes and additions to HVAC systems and general construction to allow access for performance measuring and balancing devices.

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

3.20 FINAL REPORT

A. General: Typewritten, or computer printout in letter-quality font, on standard bond paper, in 3-ring binder, tabulated and divided into sections by tested and balanced systems.

B. Include a certification sheet in front of binder signed and sealed by certified testing and balancing engineer.
   1. Include a list of instruments used for procedures, along with proof of calibration.

C. Final Report Contents: In addition to certified field report data, include the following:
   1. Pump curves.
   2. Fan curves.
   3. Manufacturers' test data.
   4. Field test reports prepared by system and equipment installers.
   5. Other information relative to equipment performance, but do not include approved Shop Drawings and Product Data.

D. General Report Data: In addition to form titles and entries, include the following data in final report, as applicable:
   1. Title page.
   2. Name and address of testing, adjusting, and balancing Agent.
   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 testing, adjusting, and balancing Agent who certifies the report.
   10. Summary of contents, including the following:
      a. Design versus final performance.
      b. Notable characteristics of systems.
      c. Description of system operation sequence if it varies from the Contract Documents.
   11. Nomenclature sheets for each item of equipment.
   12. Data for terminal units, including manufacturer, type, size, and fittings.
   13. Notes to explain why certain final data in the body of reports vary from design values.
   14. Test conditions for fans and pump performance forms, including the following:
      a. Settings for outside-, return-, and exhaust-air dampers.
      b. Conditions of filters.
      c. Cooling coil, wet- and dry-bulb conditions.
      d. Face and bypass damper settings at coils.

e. Fan drive settings, including settings and percentage of maximum pitch diameter.
f. Settings for supply-air, static-pressure controller.
g. Other system operating conditions that affect performance.

E. System Diagrams: Include schematic layouts of air and hydronic distribution systems. Present with single-line diagrams and include the following:
1. Quantities of outside, supply, return, and exhaust airflows.
2. Water and steam flow rates.
3. Duct, outlet, and inlet sizes.
4. Pipe and valve sizes and locations.
5. Terminal units.
6. Balancing stations.

F. Air-Handling Unit Test Reports:

1. Unit Data: Include the following:
a. Unit identification.
b. Location.
c. Make and type.
d. Model number and unit size.
e. Manufacturer's serial number.
f. Unit arrangement and class.
g. Discharge arrangement.
h. Sheave make, size in inches (mm), and bore.
i. Sheave dimensions, center-to-center and amount of adjustments in inches (mm).
j. Number of belts, make, and size.
k. Number of filters, type, and size.

2. Motor Data: Include the following:
a. Make and frame type and size.
b. Horsepower and rpm.
c. Volts, phase, and hertz.
d. Full-load amperage and service factor.
e. Sheave make, size in inches (mm), and bore.
f. Sheave dimensions, center-to-center and amount of adjustments in inches (mm).

3. Test Data: Include design and actual values for the following:
a. Total airflow rate in cfm (L/s).
b. Total system static pressure in inches wg (Pa).
c. Fan rpm.
d. Discharge static pressure in inches wg (Pa).
e. Filter static-pressure differential in inches wg (Pa).
f. Preheat coil static-pressure differential in inches wg (Pa).
g. Cooling coil static-pressure differential in inches wg (Pa).
h. Heating coil static-pressure differential in inches wg (Pa).
i. Outside airflow in cfm (L/s).
j. Return airflow in cfm (L/s).
k. Outside-air damper position.
l. Return-air damper position.

m. Vortex damper position.

G. Apparatus-Coil Test Reports:

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

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

1. Unit Data: Include the following:
   a. System identification.
   b. Location.
   c. Make and type.
   d. Model number and unit size.
   e. Manufacturer's serial number.
   f. Fuel type in input data.
   g. Output capacity in Btuh (kW).
   h. Ignition type.
   i. Burner-control types.
   j. Motor horsepower and rpm.
   k. Motor volts, phase, and hertz.
   l. Motor full-load amperage and service factor.

m. Sheave make, size in inches (mm), and bore.
n. Sheave dimensions, center-to-center and amount of adjustments in inches (mm).

2. Test Data: Include design and actual values for the following:
a. Total airflow rate in cfm (L/s).
b. Entering-air temperature in deg F (deg C).
c. Leaving-air temperature in deg F (deg C).
d. Air temperature differential in deg F (deg C).
e. Entering-air static pressure in inches wg (Pa).
f. Leaving-air static pressure in inches wg (Pa).
g. Air static-pressure differential in inches wg (Pa).
h. Low-fire fuel input in Btuh (kW).
i. High-fire fuel input in Btuh (kW).
j. Manifold pressure in psig (kPa).
k. High-temperature-limit setting in deg F (deg C).
l. Operating set point in Btuh (kW).
m. Motor voltage at each connection.
n. Motor amperage for each phase.
o. Heating value of fuel in Btuh (kW).

I. Fan Test Reports (Supply, return, and exhaust):

1. Fan Data: Include the following:
a. System identification.
b. Location.
c. Make and type.
d. Model number and size.
e. Manufacturer's serial number.
f. Arrangement and class.
g. Sheave make, size in inches (mm), and bore.
h. Sheave dimensions, center-to-center and amount of adjustments in inches (mm).

2. Motor Data: Include the following:
a. Make and frame type and size.
b. Horsepower and rpm.
c. Volts, phase, and hertz.
d. Full-load amperage and service factor.
e. Sheave make, size in inches (mm), and bore.
f. Sheave dimensions, center-to-center and amount of adjustments in inches (mm).
g. Number of belts, make, and size.

3. Test Data: Include design and actual values for the following:
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).

J. 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: Include the following:
    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. Design airflow rate in cfm (L/s).
    h. Design velocity in fpm (m/s).
    i. Actual airflow rate in cfm (L/s).
    j. Actual average velocity in fpm (m/s).
    k. Barometric pressure in psig (Pa).

K. Air-Terminal-Device Reports:

1. Unit Data: Include the following:
    a. System and air-handling unit identification.
    b. Location and zone.
    c. Test apparatus used.
    d. Area served.
    e. Air-terminal-device make.
    f. Air-terminal-device number from system diagram.
    g. Air-terminal-device type and model number.
    h. Air-terminal-device size.
    i. Air-terminal-device effective area in sq. ft. ((sq. m)).

2. Test Data: Include design and actual values for the following:
    a. Airflow rate in cfm (L/s).
    b. Air velocity in fpm (m/s).
    c. Preliminary airflow rate as needed in cfm (L/s).
    d. Preliminary velocity as needed in fpm (m/s).
    e. Final airflow rate in cfm (L/s).
    f. Final velocity in fpm (m/s).
    g. Space temperature in deg F (deg C).

L. System-Coil Reports (Reheat coils and water coils of terminal units):

1. Unit Data: Include the following:
    a. System and air-handling unit identification.
    b. Location and zone.
    c. Room or riser served.
    d. Coil make and size.
    e. Flow meter type.

2. Test Data: Include design and actual values for the following:
    a. Airflow rate in cfm (L/s).
    b. Entering-water temperature in deg F (deg C).
    c. Leaving-water temperature in deg F (deg C).
    d. Water pressure drop in feet of head or psig (kPa).
    e. Entering-air temperature in deg F (deg C).

f. Leaving-air temperature in deg F (deg C).

M. Packaged Chiller Reports:

1. Unit Data: Include the following:
   a. Unit identification.
   b. Make and model number.
   c. Manufacturer's serial number.
   d. Refrigerant type and capacity in gallons (L).
   e. Starter type and size.
   f. Starter thermal protection size.

2. Condenser Test Data: Include design and actual values for the following:
   a. Refrigerant pressure in psig (kPa).
   b. Refrigerant temperature in deg F (deg C0).
   c. Entering-water temperature in deg F (deg C). - EAT
   d. Leaving-water temperature in deg F (deg C). - LAT

3. Evaporator Test Reports: Include design and actual values for the following:
   a. Refrigerant pressure in psig (kPa).
   b. Refrigerant temperature in deg F (deg C).
   c. Entering-water temperature in deg F (deg C).
   d. Leaving-water temperature in deg F (deg C).
   e. Entering-water pressure in feet of head or psig (kPa).
   f. Water pressure differential in feet of head or psig (kPa).

4. Compressor Test Results: Include design and actual values for the following:
   a. Make and model number.
   b. Manufacturer's serial number.
   c. Suction pressure in psig (kPa).
   d. Suction temperature in deg F (deg C).
   e. Discharge pressure in psig (kPa).
   f. Discharge temperature in deg F (deg C).
   g. Oil pressure in psig (kPa).
   h. Oil temperature in deg F (deg C).
   i. Voltage at each connection.
   j. Amperage for each phase.
   k. The kW input.
   l. Crankcase heater kW.
   m. Chilled water control set point in deg F (deg C).
   n. Condenser water control set point in deg F (deg C).
   o. Refrigerant low-pressure-cutoff set point in psig (kPa).
   p. Refrigerant high-pressure-cutoff set point in psig (kPa).

5. Refrigerant Test Date: Include design and actual values for the following:
   a. Oil level.
   b. Refrigerant level.
   c. Relief valve setting in psig (kPa).
   d. Unloader set points in psig (kPa).
   e. Percentage of cylinders unloaded.

f. Bearing temperatures in deg F (deg C).
g. Vane position.
h. Low-temperature-cutoff set point in deg F (deg C).

N. Compressor and Condenser Reports (Refrigerant side of unitary systems, stand-alone refrigerant compressors, air-cooled condensing units, or water-cooled condensing units):

1. Unit Data: Include the following:
   a. Unit identification.
   b. Location.
   c. Unit make and model number.
   d. Manufacturer's compressor serial numbers.
   e. Compressor make.
   f. Compressor model and serial numbers.
   g. Refrigerant weight in lb (kg).
   h. Low ambient temperature cutoff in deg F (deg C).

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

O. Condenser Test Reports:

1. Unit Data: Include the following:
   a. Unit identification.
   b. Make and type.
   c. Model and serial numbers.
   d. Nominal cooling capacity in tons (kW).
   e. Refrigerant type and weight in lb (kg).
   f. Water-treatment chemical feeder and chemical.
   g. Number and type of fans.
   h. Fan motor make, frame size, rpm, and horsepower.
   i. Fan motor voltage at each connection.
   j. Sheave make, size in inches (mm), and bore.
   k. Number of belts, make, and size.

2. Air Data: Include design and actual values for the following:
   a. Duct airflow rate in cfm (L/s).
   b. Inlet-duct static pressure in inches wg (Pa).
   c. Outlet-duct static pressure in inches wg (Pa).
   d. Average entering-air, wet-bulb temperature in deg F (deg C).
   e. Average leaving-air, wet-bulb temperature in deg F (deg C).
   f. Ambient wet-bulb temperature in deg F (deg C).

P. Pump Test Reports: Calculate impeller size by plotting the shutoff head on pump curves.

1. Unit Data: Include the following:
   a. Unit identification.
   b. Location.
   c. Service.
   d. Make and size.
   e. Model and serial numbers.
   f. Water flow rate in gpm (L/s).
   g. Water pressure differential in feet of head or psig (kPa).
   h. Required net positive suction head in feet of head or psig (kPa).
   i. Pump rpm.
   j. Impeller diameter in inches (mm).
   k. Motor make and frame size.
   l. Motor horsepower and rpm.
   m. Voltage at each connection.
   n. Amperage for each phase.
   o. Full-load amperage and service factor.
   p. Seal type.

2. Test Data: Include design and actual values for the following:
   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.

Q. Fume Hood Test Reports:

1. Unit Data: Include the following:
   a. Unit identification.
   b. Location.
   c. Fume hood manufacturer
   d. Make and size.
   e. Model and serial numbers.
   f. Attach a label on the lower right hand corner of the sash on each hood clearly and legably marked with the following information: Test and balance agency, Hood No., Date, Maximum sash opening, average face velocity, lowest velocity reading, CFM, Instrument and Instrument calibration date.
2. Performance Test Data:
   a. Position of operable sash – inches
   b. Exhaust volume rate (CFM) – measured in exhaust duct. Include average duct velocity and cross sectional area of duct used for calculations
   c. Exhaust volume rate (CFM) measured at hood duct opening. Include average duct velocity and cross sectional area of duct used for calculations
   d. Sketch of hood sash opening showing center point areas and corresponding velocity readings
   e. Average face velocity. Compare with specified design face velocity.
   f. Exhaust volume rate (CFM) calculated from face velocity measurements. Compare with exhaust volumes from above.
   g. Whether reverse flows or dead air spaces were observed at hood face. (titanium tetrachloride test)
   h. Whether reverse flows were observed at each end of the working surface and across the working surface of hood. (titanium tetrachloride test).
   i. Observation and results of hood smoke test.
   j. Average face velocity with hood sash open 3 inches. Compare with specific limitations.
   k. Test summary and observations.

R. Boiler Test Reports:

1. Unit Data: Include the following:
   a. Unit identification.
   b. Location.
   c. Service.
   d. Make and type.
   e. Model and serial numbers.
   f. Fuel type and input in Btuh (kW).
   g. Number of passes.

h. Ignition type.
i. Burner-control types.
j. Voltage at each connection.
k. Amperage for each phase.

2. Test Data: Include design and actual values for the following:
a. Operating pressure in psig (kPa).
b. Operating temperature in deg F (deg C).
c. Entering-water temperature in deg F (deg C).
d. Leaving-water temperature in deg F (deg C).
e. Number of safety valves and sizes in NPS (DN).
f. Safety valve settings in psig (kPa).
g. High-limit setting in psig (kPa).
h. Operating-control setting.
i. High-fire set point.
j. Low-fire set point.
k. Voltage at each connection.
l. Amperage for each phase.
m. Draft fan voltage at each connection.
n. Draft fan amperage for each phase.
o. Manifold pressure in psig (kPa).

S. Instrument Calibration Reports: Include the following data:
1. Instrument type and make.
2. Serial number.
3. Application.
4. Dates of use.
5. Dates of calibration.

3.21 ADDITIONAL TESTS

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

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

END OF SECTION 15950