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# HVAC Functional Inspection and Testing Guide

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# ABSTRACT

This guide is developed for the Public Building Service (PBS) of the General Services Administration (GSA) for final inspection and testing of heating, ventilating, and air-conditioning (HVAC) systems in Federal buildings prior to Government acceptance. The guide describes in detail the functional inspection and testing procedures and calculations. It includes eight chapters: General, Basic Measurement, Refrigeration Plant, Heating Plant, Air Handling Equipment and systems, Building Automation Systems, Fire Safety Air Moving Systems, and Unitary Air Conditioning Equipment. The appendix contains detailed inspection checklist and test work sheets designed to be used in the field.

## Acknowledgment

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# CHAPTER 1 GENERAL

**1. Scope.** This document addresses general criteria and procedures for the functional inspection and testing of heating, ventilating, and air conditioning (HVAC) equipment and systems prior to their acceptance. Functional inspection and testing as used herein refers to those actions necessary to verify system performance and operating conditions. Commissioning process is defined by ASHRAE in ANSI/ASHRAE 1-1988 "Guideline for Commissioning of HVAC Systems" as the overall process which includes procedures and methods for documenting and verifying the performance of HVAC systems so that the systems operate in conformity with the design intent. The process starts at the pre-design phase and goes through the design phase, the construction phase, the functional performance tests of installed equipment, sub-systems and complete systems before acceptance, and ends with the post acceptance phase. The functional inspection and testing as described in this guide correspond to the functional performance tests phase of the ASHRAE commissioning process. For brevity, this functional inspection and testing will be referred to as commissioning in this document.

**2. Purpose.** Commissioning serves to improve project quality through the validation of project design and the certification of product delivery. This material is intended as a guide for evaluating and testing mechanical systems before being accepted and commissioned into building service. This document is intended to serve as a reference source to GSA and contract personnel in understanding procedural requirements associated with commissioning. Excerpts and/or reference to specific commissioning material herein can be applied within construction contract specifications as a means of defining project requirements. References can also be made within Construction Management contracts/actions to help define scope requirements.

## 3. Organization of This Guide.

3.1 This guide is organized in two parts.

3.1.1 The main body formulates basic inspection and test requirements, organized into chapters which recognize major equipment categories. Inspection and testing procedures for functional performance are separately described by EXHIBITS within each chapter. The required data, calculation equations, and acceptance criteria are given.

3.1.2 Recommended inspection check lists and test work sheets to be used in the field, are grouped in the appendicx, cross referenced by number to associated chapters.

3.2 Often used equations for calculations are called Standard Equations in this guide and are designated as SE-(number).

3.3 Often used test procedures are called Standard Test Procedures in this guide and are designated as STP-(number).

3.4 Not all procedures identified apply to all equipment and systems of a project. Project specifications and drawings should address required inspections and tests for involved equipment and systems. The inspection lists and test work sheets in the appendicx are designed for field use and should be duplicated to suit the individual project.

## 4. The Commissioning Team.

4.1 The commissioning team (often abbreviated "the Team" in this guide) is the team which represents Public Building Service (PBS) in the commissioning process. The commissioning team could be composed of PBS construction engineer(s), agency operation and maintenance representatives, construction (quality) manager, the contract architect/engineer, and/or specialty consultants. Depending on the sophistication of the equipment and systems, the Team may also include designers, fire/safety officers, equipment and system specialists, and/or supplemental inspection contract agents.

4.2 The commissioning team must be able to understand and to interpret contract specifications and drawings. However, the team has no authority to alter the requirements of these documents.

4.3 Testing and operation of equipment and systems during commissioning is the responsibility of the construction contractor or his representatives (see paragraph 5. below). The Team shall inspect and verify that equipment and systems are installed in accordance with the contract documents and witness all tests conducted by the contractor and perform verifications and documentation.

4.4 The project contract should require the contractor to assist the commissioning team in inspections when needed (e.g. access to inside boilers).

4.5 The PBS construction engineers will coordinate the commissioning process. Final responsibility for acceptance of the HVAC system shall be as designated by the Contracting Officer.

## 5. Designated Inspection and Testing Agent.

5.1 Designated testing agents are the persons actually operating the equipment/systems and performing tests during commissioning. Contractually, this will almost always be the installing contractor and/or manufacturer of the installed equipment/system.

5.2 Designated testing agents may be employees of the equipment manufacturers, independent testing laboratories or agencies, and other qualified specialists. Project specifications usually specifies the qualifications of testing inspection agents. For major equipment testing, such as for large chillers and boilers, it may be appropriate to require factory personnel of the equipment manufacturer as the testing agent.

**6. Codes, Regulations, and Standards.** Where codes, regulations, and standards are cited in this guide and its appendices, the latest editions shall be used unless construction contract specifications direct the specific use of an earlier version. Relevant standards of the following organizations are listed in the equipment chapters as general references for interested readers.

a. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

b. American Society of Mechanical Engineers (ASME).

c. Air-Conditioning and Refrigeration Institute (ARI).

d. National Fire Protection Association (NFPA).

e. Underwriters Laboratories (UL).

f. Sheet Metal Contractors National Association (SMACNA).

**7. General Principles.** Inspect and test HVAC equipment and systems to verify that construction, installation, and performance is in accordance with the project specifications, drawings, approved submittal documents, and generally recognized good practices.

7.1 All components and systems must meet project specifications drawings and contract requirements.

7.2 Since product data, shop drawings, and wiring diagrams of major equipment are typically required by construction contract documents to be submitted for approval before installation, the following should be done.

7.2.1 For the equipment and systems whose submittals are approved, verify that the installation meets contract requirements.

7.2.2 For the equipment and systems whose submittals are approved as noted, pay special attention to the items noted as conditions of approval.

7.2.3 In no case should rejected equipment and systems be installed.

7.2.4 For equipment and systems where submittals are not required, verify the quality and quantity as specified.

7.2.5 Verify the performance of equipment and systems to meet specification requirements.

7.3 The inspection and functional testing procedures outlined in this guide assumes that project construction is virtually complete, including balancing and adjusting of all equipment and support systems.

7.4 Any equipment which has been used extensively before commissioning inspection and testing must be cleaned or reconditioned to meet the project specification requirements.

7.5 Temporary measures (such as temporary piping hookups) may be required for inspection and testing. Unless otherwise directed in design documents, temporary measures shall be removed and the systems restored to their specification required permanent conditions after inspection and testing are performed.

7.6 The specification of each project must specify the scope of functional tests required for the project. Selected inspection and test procedures from this guide must be incorporated into the project specification. As this guide gives general principals for project inspection and testing, special project equipment/system may require different commissioning procedures. The commissioning team must give individual planning to each project before field inspection and testing.

## 8. Procedures and Sequences.

8.1 Inspection. Inspection is the first step in commissioning any equipment and system. Observe and note damage, rust, omissions, and unsafe conditions. For equipment and systems which have been required to submit shop drawings for approval, it is necessary to verify that products and installation are in accordance with the design and approved submittals.

8.2 Steady-state tests. Steady-state tests are usually used to verify the design capacities and conditions of the equipment and systems. These tests should generally be performed after inspection procedures are completed. The exact kind of tests to be performed depend on what the contract documents require. If steady-state tests do not meet project requirements, operation tests (see paragraph 8.3 below) should not be performed.

8.3 Operation tests. These tests should be performed after the steady-state tests are performed. All designated modes of operation shall be witnessed to verify proper sequencing, control stability, and assurance of system performance. These tests can usually be used to predict future operation deficiencies.

8.4 Factory tests. Where specifications require factory testing of either the installed item or a similar item, copies of test reports must be provided to the commissioning team.

8.5 Inspections and tests may be performed concurrently, if time and costs may be saved.

## 9. Preparation and Coordination.

9.1 The commissioning team must become familiar with contract documents, design intent, project specification, drawings, manufacturer's installation instructions, and manufacturer's operation and maintenance manuals.

9.2 The commissioning team shall coordinate with the project manager and/or construction engineer to review inspection records and to obtain pertinent information regarding the history of construction.

9.3 The commissioning team shall plan, prepare and review the test procedures for the equipment and systems to be tested and coordinate the tests.

9.4 If a Quality Control Plan is required of the contractor, consult scheduling and other requirements for involved inspections and tests.

**10. Witness of Tests.** The commissioning team must witness all tests.

**11. Maintenance and Operation Manuals.** Before commissioning inspection, be certain that maintenance and operating manuals have been delivered to the Government in accordance with contract requirements.

**12. Spare Parts.** During the inspection, verify the quality and quantity of spare parts as may be required by project specifications.

## 13. Documentation.

13.1 The testing inspection agent and the commissioning team shall record and maintain detailed inspection and testing data. The data recorded shall be comprehensive, concise, and precise.

13.2 All data must be recorded as soon as possible during the course of the inspection and testing.

13.3 All documentation shall have the date, time, and names of persons participating in the inspection and testing.

13.4 All test instruments shall be documented for valid calibration.

13.5 The recommended data recording work sheets and inspection check lists are shown in the appendices cross referenced to the various chapters of this guide where inspection and testing procedures/criteria are detailed.

13.6 The commissioning team should be aware that inspection and testing records may be used as evidence in legal disputes.

13.7 PBS construction engineers of the commissioning team will receive the final documentation for the Government.

## 14. System Capacity.

14.1 The capacities of HVAC systems and components at full load shall be not less than those indicated in contract documents, project specifications and drawings.

14.2 At full load conditions, the space temperature shall not differ from design set temperature +/- set point control tolerances.

**15. System Energy Consumption.** The installed HVAC system must operate efficiently. The energy consumption rates shall not be greater than the full and part load energy rates as indicated in the contract documents, project specifications and drawings.

## 16. Safety.

16.1 All equipment and systems must be able to operate safely for the system operating personnel, building occupants, and the public.

16.2 Necessary precautions must be taken during inspection and testing to prevent injury to personnel and damage to equipment. These shall include, but not limited to:

16.2.1 Providing fire extinguishing equipment.

16.2.2 Presence of all factory recommended guards to belt drives, rotating shafts, and electrical leads.

16.2.3 No clutter of construction debris.

16.2.4 No ongoing work by other trades in immediate areas.

16.2.5 Lock-out capability to all secured electrical circuits.

16.2.6 Personnel safety gear, including acoustic ear protection, safety glass and hard hats.

16.2.7 Make no overrides to equipment safety controls, except as required to test secondary safety control/operation.

16.2.8 Coordinate all temporary control modifications and equipment tests with the Building Manager and Construction Engineer.

**17. Notation/Abbreviation.** Abbreviations for organizations contained in this guide are listed in the following table:

| | |
|---|---|
| AABC | Associated Air Balance Council |
| ACCA | Air-Conditioning Contractors of America |
| ADA | Air Diffusion Council |
| AGA | American Gas Association |
| AHAM | Association of Home Appliance Manufacturers |
| AMCA | Air Movement and Control Association |
| ANSI | American National Standards Institute |
| ARI | Air-Conditioning and Refrigeration Institute |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| ASME | The American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| CTI | Cooling Tower Institute |
| HYD I | Hydronics Institute |
| IEEE | Institute of Electrical and Electronic Engineers |
| ISA | Instrument Society of America |
| NEBB | National Environmental Balancing Bureau |
| NEMA | National Electrical Manufacturers Association |
| NFPA | National Fire Protection Association |
| SMACNA | Sheet Metal and Air Conditioning Contractors National Association |
| UL | Underwriters Laboratories, Inc. |

# CHAPTER 2 BASIC MEASUREMENT

**1. Scope.** This chapter provides general instrumentation requirements and basic measurement techniques for commissioning tests.

**2. General Requirements.** Instrumentation selection and measurement techniques shall generally comply with recommendations of the following organizations:

a. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

b. American Society of Mechanical Engineers (ASME).

c. Instrument Society of America (ISA).

d. American Society of Testing and Materials (ASTM).

## 3. Calibration of Test Instruments.

3.1 All test instruments must have valid calibration.

3.2 Calibration of test instruments may be performed by their manufacturers with calibration certificates, by companies or government agencies regularly engaged in calibrating similar instruments, or as witnessed during testing in accordance with calibrating procedures recommended by the instrument manufacturer or organizations listed in paragraph 2. above.

## 4. Field Test Instruments.

4.1 The minimum accuracy requirements for equipment testing are listed under the equipment testing chapters of this guide. Field test instruments must meet these minimum requirements.

4.2 The expected accuracies of the most commonly used field test instruments and some precautions for their use are listed in EXHIBIT 2-A.

4.3 The 1989 ASHRAE Handbook of Fundamentals, Chapter 13 also lists the commonly used test instruments and their associated ranges and accuracies.

## 5. Permanently Installed Field Instruments.

5.1 Permanently installed instruments may be available as part of the basic construction contract requirements. If identified for the purpose of commissioning, these sensors, transmitters, and wiring, must be calibrated and inspected to insure that they will perform properly. It is extremely important that special attention be paid to their installation locations and details during the inspection. Strict adherence to the recommendations of the manufacturers or those of the organizations of paragraph 2. above must be observed.

5.2 Specific recommendations of installation and testing of these instruments may be found in the Appendices.

5.3 Permanently installed field instruments may be used for commissioning tests, if they are proven to meet accuracy requirements.

## 6. Standard Equations.

6.1 Standard equations shall be used as referenced herein for calculations which evaluate equipment and system performance.

6.2 Standard equations are listed in EXHIBIT 2-B.

## 7. Standard Test Procedures.

7.1 During equipment and system tests, standard test procedures shall be adhered to as much as possible.

7.2 Standard test procedures are listed in EXHIBIT 2-C as well as other chapters of this guide where equipment and system test procedures are described.

7.3 Discussion of error analysis may be found in ASHRAE 1989 Fundamentals Handbook, Chapter 13, ANSI/ASHRAE Standard 114 (Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilating, Air Conditioning and Refrigeration Systems).

## EXHIBIT 2-A FIELD TEST INSTRUMENTS

### 1. Selection of instruments.

1.1 A general principal of selecting instruments is to match the minimum instrument accuracies to the allowed measurement tolerances. The required measurement tolerances are specified in contract documents or given in testing procedures of this guide.

1.2 In order to minimize the instrumentation error, the ranges of the instruments should be selected close to the intended measurement without chances of overloading the instruments. Many instrument accuracies are expressed in percent of full scale readings which will result in very large errors when the measured quantities are not close to the full scale readings. In such cases, instrument of different ranges should be used.

**2. Field test instruments.** The following instruments can easily be carried and used in the field. Listed are the accuracies of these instruments and precautions of their use. These accuracies are considered to be easily attainable.

2.1 Temperature.

2.1.1 Portable digital thermometer. Use to measure air or water temperature. Accuracy +/- 0.3 °C (0.5 °F).

2.1.1.1 Use contact grease for thermometer well applications.

2.1.1.2 Do not take measurements in stagnant areas.

2.1.2 Mercury-in-glass thermometer. Available in various grades and graduations. Select thermometer to suit required accuracy. Thermometers graduated in 0.1 °C (0.2 °F) is easily obtainable for temperature from 0 to 149 °C (32 to 300 °F).

2.1.2.1 May be used for high accuracy applications and for calibrating other temperature instruments. Relatively long response time.

2.1.2.2 Careful reading of scale is required. Use magnifying glass, if necessary.

2.1.2.3 If partial-immersion thermometer is used, align the immersion line with the fluid being measured.

2.1.2.4 Adjustment for immersion may be necessary for high accuracy applications.

* Using total-immersion thermometer partially immersed:

$$\text{correction} = 0.00016\ n\ (t_1 - t),\ \text{(For SI)}$$
$$= 0.00009\ n\ (t_1 - t),\ \text{(For Customary)}$$

where n = mercury column length outside measuring fluid, expressed in temperature
$t_1$ = indicated temperature, °C (°F)
t = average stem temperature, measured with an auxiliary thermometer, °C (°F)

* Using partial-immersion thermometer in an environment where the stem temperature differs substantially from the stem temperature marked on the thermometer:

$$\text{correction} = 0.00016\ n\ (t_1 - t),\ \text{(For SI)}$$
$$\text{or}\quad 0.00009\ n\ (t_1 - t),\ \text{(For Customary)}$$

where n = mercury length above immersion line, expressed in temperature
$t_1$ = stem temperature marked on thermometer, °C (°F)
t = average stem temperature, measured with an auxiliary thermometer, °C (°F)

2.1.2.5 See paragraph 2.1.1 above for use precautions.

2.1.2.6 If mercury column separation has taken place, the gaps must be eliminated by carefully heating or cooling the mercury bulb until the gaps reach the upper or lower chamber (consult thermometer manufacturer or thermometer care book for details). The thermometer must be recalibrated.

2.1.3 Electric resistance box. Use to simulate electric resistance for calibrating resistance temperature detector (RTD) in critical applications, such as for differential temperature measurement in chilled water lines). Accuracy 0.1 ohm. Contact terminals must be polished after extended period of storage to minimize measurement errors.

2.2.4 Thermocouple indicator/simulator. Use for indicating temperature from thermocouple input or simulating thermocouple output. Accuracy of +/- 0.5 °C (0.9 °F) may be achieved with factory calibrated thermocouple wires.

2.1.5 Infrared thermometer. Use for testing steam leaking. Accuracy +/- 2% full scale.

2.2 Humidity.

2.2.1 Sling and aspirated psychrometer. Accuracy +/- 3% RH. (The accuracy of sling psychrometer is limited by the thermometer length and graduation. Accuracy of +/- 0.6 °C (1 °F) wet bulb, equivalent to approximately 3.5% RH at 25 °C (77 °F) and 50%RH, can be expected.)

2.2.1.1 Wicks must be clean and only distilled water is used for the wet-bulb thermometer. Be sure the wicks are fully wet during measurement.

2.2.1.2 The air velocity should be at 3 - 5 m/s (590 - 984 ft/min) across the wet bulb. For the sling type, swing the psychrometer to produce the recommended speed.

2.2.1.3 Thermometers need calibration.

2.2.1.4 Sling psychrometer is simple in construction and easy to use. It should be considered as an essential instrument in all commissioning work.

2.2.1 Portable digital humidity meter. Accuracy +/- 3% RH.

2.2.1.1 Avoid high humidity environment of over 95% RH or low humidity environment of under 20% RH.

2.2.1.2 Must be recalibrated frequently.

2.3 Pressure.

2.3.1 U-tube manometer. Accuracy +/- 7 Pa (0.03 in. of water).

2.3.1.1 Must use the right density fluid.

2.3.1.2 Leveling of manometer is important.

2.3.1.3 Be careful reading scales (avoid parallax errors).

2.3.1.4 When using a static pressure tip for measuring air, the location of the sensing tip must be selected that no velocity component of the air flow affects the readings.

2.3.2 Inclined manometer. Accuracy +/- 2.5 Pa (0.01 in. of water). Same application precautions as described for U-tube manometer.

2.3.3 Bourdon-tube and bellow type pressure and compound gage. Accuracy +/- 0.1% full scale.

2.3.3.1 Must be calibrated periodically.

2.3.3.2 Be aware of possible errors caused by parallax.

2.3.3.3 Must not subject to overpressure.

2.3.3.4 Be aware of possible error caused by elevation of gage.

2.3.4 Diaphragm air pressure gage. Accuracy +/- 2% full scale. Same application precautions as paragraph c. above.

2.3.5 Pressure calibrator.

2.3.5.1 For simulating pneumatic control systems - range to 357 kg/m$^3$ (20 psig). Accuracy +/- 0.5% full scale.

2.3.5.2 For simulating duct air pressure - range depends on application.

2.3.5.3 Commonly used "squeeze bulb" is not a good instrument for creating and maintaining a desired pressure and should not be used for commissioning work.

2.3.6 Pressure readings for air or water are often fluctuating. Applying pressure restriction devices between the test instruments and the tested equipment usually helps. If the instrument readings still fluctuate, the average of several readings must be used.

2.4 Velocity and flow rate.

2.4.1 Pitot tube.

2.4.1.1 In combination with appropriate pressure measuring instrument to measure air velocity. For example, inclined manometers with accuracy of 1.2 Pa (0.005 in. of water) may be used to measure air velocity down to 3 m/s (590 ft/min) to give results within 15% accuracy.

2.4.1.2 Selection of traverse location is important. Avoid locations having unstable air flow profiles. A minimum distance of 7.5 diameters down stream of duct fittings or 1.5 diameters after straightening vanes is preferred.

2.4.1.3 In calculating the average velocity cf air in a duct, average the individual velocities of the traverse, not the velocity heads (pitot readings).

2.4.2 Air measurement station. A permanently placed in-duct unit consisting of numerous pitot tube sensors manifolded together with pressure gages or other readout devices to give readings of velocity pressure, velocity, or air flow rate. Units equipped with air straighteners upstream of pressure sensing tips are available.

2.4.2.1 Data of accuracy and air friction for these units may be obtained from manufacturer. +/- 5% reading is usually obtainable.

2.4.2.2 Site conditions are critical for good measurement. Unit manufacturers usually make recommendations for location selections. Units with air straighteners are required should duct placement not match 2.4.1.2.

2.4.3 Heated thermocouple anemometer. May measure down to 0.05 m/s (10 ft/min) air velocity. Accuracy +/- 3% of reading or no less than +/- 0.01 m/s (2 ft/min). Correction for air temperature and humidity may be necessary. Consult manufacturer's instructions.

2.4.4 Rotating vane anemometer.

2.4.4.1 May be used to measure air velocities lower than for pitot tube at locations such as coil face or grille face. Accuracy is +/- 10% of reading and is considerably lower than that of pitot tube at ideal locations and velocities.

2.4.4.2 Instrument must be calibrated for the entire range of the intended velocity.

2.4.5 Flow hoods are used to measure volume flow of air from devices such as air diffusers and registers. Accuracy depends on the velocity reading instrument used. The hood and reading instrument must be calibrated as a unit.

2.4.6 Positive displacement meters measure volumetric flow rate of gas and liquid. Accuracy +/- 1% full scale.

2.5 Electric power, energy, voltage, and current.

2.5.1 Portable kilowatt meter/kilowatt-hour meter. Accuracy +/- 1% of reading at unity power factor.

2.5.2 Electric clamp-on meter (for motor current and voltage measurement). Accuracy +/- 2% full scale.

2.5.3 Some instruments may require zeroing before measurement. Frequent calibration may be needed.

2.6 Rotation speed.

2.6.1 Contact tachometer. Accuracy +/- 1 rpm. Exercise caution in taking readings. Guards for drive mechanisms should have provisions to remain in place while making measurements.

2.6.2 Photo tachometer. Accuracy +/- 1.5% full scale.

2.6.3 Stroboscope. Accuracy +/- 3% full scale.

2.7 Portable temperature/humidity recorder. For recording space temperature and humidity over a minimum period of one week. Accuracy depends on the quality of the instrument and the resolution of the scale. Generally, +/- 2% and 4% of full scale may be achieved for temperature and humidity measurements, respectively. Should be calibrated periodically.

2.8 Portable refrigerated liquid bath. For calibrating temperature instruments. Must provide +/- 0.01 °C (0.02 °F) temperature stability. Minimum temperature range -20 - 100 °C (-4 - 212 °F).

2.9 Refrigerant leak detector. Automatic electronic halogen leak detector for continuous refrigeration system leak detection. Sensitivity 3ppm.

2.10 Orsat flue gas analyzer. For measuring and analyzing flue gas. Measures oxygen, carbon dioxide, and carbon monoxide components in the combustion product.

2.11 Flow measurement of liquid and superheated steam may be performed using pressure instruments connected to pressure taps of built-in flow measuring device such as orifice plate, flow nozzles, and venturies. See pressure section for accuracy for manometers, pressure gages, etc.

**3. Instrumentation instructions.** Whenever the instructions or user manuals are available from the instrument manufacturers, they should be closely followed.

## EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS

**1. Air.** Standard air is defined as air having a density of 1.20 $kg/m^3$ (0.075 $lb/ft^3$). This density is approximately that of dry air at a barometric pressure of 101.039 kPa (29.92 in. of mercury) and a temperature of 21 °C (70 °F). Most construction documents and manufacturer's equipment data express air properties in terms of standard air. When air flow rate measurement is performed at conditions considerably different from these conditions, it may be necessary to adjust to standard conditions in order to compare the measured results with specified quantities.

If the temperature of air is higher than 29 °C (85 °F) or lower than 13 °C (55 °F), the measured volume flow rate should be adjusted to that of the standard air by using SE-7 and SE-14 (see example 2). Without adjusting between these temperatures, the maximum error is 3%.

The effect of static pressure inside an air duct or air handling apparatus can usually be ignored in air calculations (e.g. the error of air density for ignoring a 995 Pa (4 in. of water) static pressure under 101.039 kPa (29.92 in. of mercury) barometric pressure is less than 1%). Barometric pressure changes have far more influence on air properties and should be used in all pertinent calculations. The commissioning team should note under what conditions the air quantities are specified in the construction documents (at standard conditions or at high elevation conditions). The air equations given in this EXHIBIT may be used directly if the barometric pressure is measured during the commissioning. If barometric pressure is not measured, an estimate of total air pressure may be made by using the following standard atmospheric data:

| Altitude, m (ft) | Pressure, kPa (in. Hg) |
|---|---|
| 152 (500) | 99.21 (29.38) |
| 305 (1000) | 97.46 (28.86) |
| 610 (2000) | 93.94 (27.82) |
| 914 (3000) | 90.57 (26.82) |
| 1219 (4000) | 87.19 (25.82) |
| 1524 (5000) | 84.08 (24.90) |
| 1829 (6000) | 80.98 (23.98) |
| 2134 (7000) | 77.97 (23.09) |

For sample air property calculations at high altitude, see Example 1 below.

**2. Air property equations.** The following air property equations are presented for reference for possible use during commissioning. The theory and derivation of these equations may be found in most engineering handbooks of thermodynamics, and fluid mechanics, for example, the ASHRAE 1989 Handbook of Fundamentals.

2.1 Saturated water vapor pressure. Knowing the dry-bulb temperature of the air, the saturated water vapor pressure may be found from steam tables (e.g. 1989 ASHRAE Fundamentals Handbook, Chapter 6, Table 2) or using the following equation. The equation yields less than 1% error if the dry-bulb temperature is above -1 °C (30 °F).

$$P_{sw} = 3376.85 \times e^{(15.4636 - 7284/(1.8 \times Td + 424))} \quad \text{(For SI)} \qquad \text{SE-1}$$

$$P_{sw} = e^{(15.4636 - 7284/(Td + 392))} \quad \text{(For Customary)}$$

where constant e = exp 1 = 2.71828

2.2 Vapor pressure. Knowing the relative humidity of air (by direct measurement) and saturated vapor pressure (SE-1), the vapor pressure of air may be calculated.

$$P_w = RH \times P_{sw} \qquad \text{SE-2}$$

2.3 Humidity ratio. Humidity ratio of air may be calculated by knowing the barometric pressure (by direct measurement) and air vapor pressure (SE-2).

$$W = 0.622 \times P_w \,/\, (P_b - P_w) \qquad \text{SE-3}$$

2.4 Enthalpy of air. Enthalpy of air is calculated from air humidity ratio (SE-3) and dry-bulb temperature.

$$H = T_d + W\,(2501 + 1.805 \times T_d) \quad \text{(For SI)} \qquad \text{SE-4}$$

$$H = 0.24 \times T_d + W\,(1061 + 0.444 \times T_d) \quad \text{(For Customary)}$$

2.5 Specific volume of air. To calculate specific volume of moist air knowing barometric pressure, dry bulb temperature, and humidity ratio.

$$v = \frac{287.055\,(273.15 + T_d)}{P_b}\,(1 + 1.6078 \times W) \quad \text{(For SI)} \qquad \text{SE-5}$$

$$v = \frac{0.7543\,(459.67 + T_d)}{P_b}\,(1 + 1.6078 \times W) \quad \text{(For Customary)}$$

2.6 Density of moist air.

$$D = (1 + W) \,/\, v \qquad \text{SE-6}$$

2.7 Adjusting density of air. Air density may be adjusted from one set of temperature and pressure to another set.

$$\frac{D_1}{D_2} = \left(\frac{P_1 + P_{b1}}{P_2 + P_{b2}}\right)\left(\frac{T_{d2} + 273.15}{T_{d1} + 273.15}\right) \quad \text{(For SI)} \qquad \text{SE-7}$$

$$\frac{D_1}{D_2} = \left(\frac{P_1 + 13.6\ P_{b1}}{P_2 + 13.6\ P_{b2}}\right)\left(\frac{T_{d2} + 459.67}{T_{d1} + 459.67}\right) \quad \text{(For Customary)}$$

2.8 Air velocity by pitot-static and reverse pitot measurement. Velocity pressure is directly obtained by measuring of total pressure and static pressure with a pitot tube.

$$P_v = P_t - P_s \qquad \text{SE-8}$$

Velocity of air stream may be calculated from velocity pressure.

$$V = 139.91\ (P_v\ /\ D)^{1/2} \quad \text{(For SI)} \qquad \text{SE-9}$$

$$V = 1096.5\ (P_v\ /\ D)^{1/2} \quad \text{(For Customary)}$$

At 101.325 kPa (29.921 in. Hg) atmospheric pressure and 21.1 °C (70 °F) air temperature, the air density is 1.20 kg/$m^3$ (0.075 lb/$ft^3$). The equation reduces to:

$$V = 127.63\ (P_v)^{1/2} \quad \text{(For SI)} \qquad \text{SE-10}$$

$$V = 4004\ (P_v)^{1/2} \quad \text{(For Customary)}$$

The average velocity of several velocity-pressure readings is calculated by (at standard air conditions):

$$V = 127.63\ \frac{\text{sum}\ [(P_v)^{1/2}]}{\text{no. of readings}} \quad \text{(For SI)} \qquad \text{SE-11}$$

$$V = 4004\ \frac{\text{sum}\ [(P_v)^{1/2}]}{\text{no. of readings}} \quad \text{(For Customary)}$$

2.9 Volume flow rate.

$$Q = A \times V \qquad \text{SE-12}$$

2.10 Relationship of volume flow rate, velocity, and density.

$$Q_1\ /\ Q_2 = V_1\ /\ V_2 = D_2\ /\ D_1 \qquad \text{SE-13}$$

2.11 Mass flow rate.

$$M = Q \times D = Q / v \qquad \text{SE-14}$$

2.12 Duct system air friction. The following equation may be used in most applications to plot duct system curves or to calculate new air friction from known air flow rates and air friction.

$$(Q_1 / Q_2)^2 = (F_1 / F_2) \qquad \text{SE-15}$$

2.13 Conversion from gage to absolute pressure.

$$P_a = P_b + P_g \qquad \text{SE-16}$$

Symbols for air:
- A = net cross sectional area of duct, $m^2$ ($ft^2$)
- D = density of air, $kg/m^3$ ($lb/ft^3$)
- F = air friction (or pressure drop), m (in.) of water
- H = enthalpy of air, kJ/kg of air (Btu/lb of air)
- M = air mass flow rate, kg/s (lb/min)
- P = static pressure of air, kPa (in. of water)
- $P_a$ = absolute pressure
- $P_b$ = barometric pressure, kPa (in. of Hg)
- $P_g$ = gage pressure
- $P_s$ = static pressure, m (in.) of water
- $P_{sw}$ = saturated vapor pressure, Pa (in. of Hg)
- $P_t$ = total pressure, m (in.) of water
- $P_v$ = velocity pressure, m (in.) of water
- $P_w$ = vapor pressure of air, Pa (in. of Hg)
- Q = volume flow rate, $m^3/s$ ($ft^3/min$)
- RH = relative humidity of air, %
- $T_d$ = dry-bulb temperature of air, °C (°F)
- v = specific volume of moist air, $m^3/kg$ of dry air ($ft^3/lb$ of dry air)
- V = air velocity, m/s (ft/min)
- W = humidity ratio, kg (lb) of vapor/kg (lb) of dry air
- 1, 2 = at 1 or 2 conditions

Example 1 - air property calculations:

Assume that the following air properties are measured: $T_d$ = 26.7 °C (80 °F), RH = 61%, and $P_b$ = 84.09 kPa (24.90 in. of Hg) (at approximately 1524 m (5000 ft) above sea level).

Saturated vapor pressure (SE-1):

$$P_{sw} = 3376.85 \text{x} e^{(15.4636-7284/(1.8 \text{x} 26.7+424))} = 3.491 \text{ kPa} \quad \text{(For SI)}$$

$$P_{sw} = e^{(15.4636-7284/(80+392))} = 1.032 \text{ in. Hg} \qquad \text{(For Customary)}$$

Vapor pressure (SE-2):

$$P_w = 0.61 \times 3491 = 2.130 \text{ kPa} \qquad \text{(For SI)}$$

$$P_w = 0.61 \times 1.032 = 0.6296 \text{ in. Hg} \qquad \text{(For Customary)}$$

Humidity ratio (SE-3):

$$W = 0.622 \left(\frac{0.6296}{24.90 - 0.6296}\right) = 0.01614 \text{ kg (lb) of moisture/kg (lb) of dry air}$$

Enthalpy of air (SE-4):

$$H = 26.7 + 0.01614 (2501 + 1.805 \times 26.7) = 67.84 \text{ kJ/kg}$$

$$H = 0.24 \times 80 + 0.01614 (1061 + 0.444 \times 80) = 36.90 \text{ Btu/lb dry air}$$

Specific volume of air (SE-5):

$$v = \frac{287.055 (273.15 + 26.7)}{84090} (1 + 1.6078 \times 0.01614)$$
$$= 1.050 \text{ m}^3\text{/kg dry air}$$

$$v = \frac{0.754 (460 +80)}{24.90} (1 + 1.6078 \times 0.01614)$$
$$= 16.78 \text{ ft}^3\text{/lb dry air}$$

Density of air (SE-6):

$$D = \frac{1 + 0.01614}{1.050} = 0.9678 \text{ kg/m}^3$$

$$D = \frac{1 + 0.01614}{16.78} = 0.06056 \text{ lb/ft}^3$$

Example 2 - adjustment of measured air flow rates:

Air flow rate is measured in a duct with pitot tube and a pressure measuring device to be 4.248 $m^3/s$ (9000 $ft^3/min$). The temperature of air at the place of flow measurement is 48.9 °C (120 °F). The barometric pressure is at standard atmospheric pressure 101.325 kPa (29.92 in. Hg). The volume flow rate at standard air conditions is (SE-7 and SE-13):

$$Q = 4.248 \times \frac{273.15 + 21.1}{273.15 + 48.9} = 3.881 \ m^3/s$$

$$Q = 9000 \times \frac{460 + 70}{460 + 120} = 8224 \ ft^3/min$$

## 3. Fan calculations.

### 3.1 Definition of fan pressure.

3.1.1 The basic pressure equation in any duct is SE-8, i.e.,

$P_t = P_s + P_v$
where Pt, Ps, and Pv can all be measured.

3.1.2 Fan pressure by definition:

Fan total pressure:

$$P_{tf} = P_{t(out)} - P_{t(in)} \qquad \text{SE-17}$$

Fan velocity pressure:

$$P_{vf} = P_{v(out)} \qquad \text{SE-18}$$

Fan static pressure:

$$P_{sf} = P_{tf} - P_{vf} \qquad \text{SE-19}$$
$$= P_{t(out)} - P_{t(in)} - P_{v(out)}$$
$$= P_{s(out)} + P_{v(out)} - P_{t(in)} - P_{v(out)}$$
$$P_{sf} = P_{s(out)} - P_{t(in)} \qquad \text{SE-20}$$

Note that fan static pressure is not the difference between the static pressures at fan outlet and inlet.

3.1.3 Special cases:

3.1.3.1 Fan with inlet duct only.

$P_{s(out)} = 0$

$$P_{sf} = - P_{t(in)} \qquad \text{SE 21}$$

Note that it is always negative.

$$P_{tf} = P_{t(out)} - P_{t(in)}$$
$$= P_{v(out)} - P_{t(in)} \qquad \text{SE-22}$$

3.1.3.2 Fan without a inlet duct.

$$P_{s(in)} = P_{v(in)} = P_{t(in)} = 0$$

$$P_{tf} = P_{t(out)} - P_{t(in)} = P_{t(out)} \qquad \text{SE-23}$$

$$P_{sf} = P_{tf} - P_{vf} = P_{t(out)} - P_{v(out)}$$
$$= P_{s(out)} \qquad \text{SE-24}$$

3.1.3.3 Fan with both inlet and outlet ducts.

$$P_{tf} = P_{t(out)} - P_{t(in)} \qquad \text{SE-25}$$

$P_{sf} = P_{s(out)} - P_{t(in)}$ same as SE-20

Symbols: all units in Pa (in. of water)

$P_{t(out)}$ = outlet total pressure
$P_{s(out)}$ = outlet static pressure
$P_{v(out)}$ = outlet velocity pressure
$P_{t(in)}$ = inlet total pressure
$P_{s(in)}$ = inlet static pressure
$P_{v(in)}$ = inlet velocity pressure
$P_{tf}$ = fan total pressure
$P_{sf}$ = fan static pressure
$P_{vf}$ = fan velocity pressure

3.2 Fan equations.

3.2.1 For the same fan and air density:

$$Q_1 = Q_2 \times (N_1 / N_2) \qquad \text{SE-26}$$

$$P_{t1} \text{ or } P_{s1} = (P_{t2} \text{ or } P_{s2}) \times (N_1 / N_2)^2 \qquad \text{SE-27}$$

$$W_1 = W_2 \times (N_1 / N_2)^3 \qquad \text{SE-28}$$

$$P_{t1} \text{ or } P_{s1} = (P_{t2} \text{ or } P_{s2}) \times (Q_1 / Q_2)^2 \qquad \text{SE-29}$$

$$W_1 = W_2 \times (Q_1 / Q_2)^3 \qquad \text{SE-30}$$

$$W_1 = W_2 \times \left(\frac{P_{t1} \text{ or } P_{s1}}{P_{t2} \text{ or } P_{s2}}\right)^{(3/2)} \qquad \text{SE-31}$$

3.2.2 For the same fan and speed, at varying air density:

$$\frac{P_{t1} \text{ or } P_{s1}}{P_{t2} \text{ or } P_{s2}} = \frac{D_1}{D_2} \qquad \text{SE-32}$$

$$W_1 / W_2 = D_1 / D_2 \qquad \text{SE-33}$$

3.2.3 Fan efficiency:

$$(e)_t = P_t \times Q / W \quad \text{(For SI)} \qquad \text{SE-34}$$

$$(e)_t = P_t \times Q / 6350\ W \quad \text{(For Customary)}$$

$$(e)_s = P_s \times Q / W \quad \text{(For SI)} \qquad \text{SE-35}$$

$$(e)_s = P_s \times Q / 6350\ W \quad \text{(For Customary)}$$

Symbols:
- $D$ = air density, kg/m$^3$ (lb/ft$^3$)
- $(e)_s$ = fan static efficiency, %
- $(e)_t$ = fan total efficiency, %
- N = fan speed, RPM
- $P_s$ = static pressure, Pa (in. of water)
- $P_t$ = total pressure, Pa (in. of water)
- Q = volume flow rate, m$^3$/s (ft$^3$/min)
- W = power input, W (hp)
- 1, 2 = at 1 or 2 conditions

# 4. Flow rate measurement for water, air, steam, or refrigerant.

## 4.1 Orifice, nozzle, and venturi meters.

$$M = 0.01252\ (C\ Y\ d^2\ Fa)\ \left[\frac{D\ hw}{(1 - B^4)}\right]^{(1/2)} \quad \text{(For SI)} \qquad \text{SE-36}$$

$$M = 358.93\ (C\ Y\ d^2\ Fa)\ \left[\frac{D\ hw}{(1 - B^4)}\right]^{(1/2)} \quad \text{(For Customary)}$$

$$Q = 0.01252\ (C\ Y\ d^2\ Fa)\ \left[\frac{hw}{D\ (1 - B^4)}\right]^{(1/2)} \quad \text{(For SI)} \qquad \text{SE-37}$$

$$Q = 358.93\ (C\ Y\ d^2\ Fa)\ \left[\frac{hw}{D\ (1 - B^4)}\right]^{(1/2)} \quad \text{(For Customary)}$$

If data from ASHRAE standards are used for calculation of flow rates, the discharge coefficient C is combined with the term $(1/(1 - B^4)^{(1/2)})$ and given as flow coefficient K. These equations become:

$$M = 0.01252\ (K\ Y\ d^2\ Fa)\ (\ D\ hw\ )^{(1/2)} \quad \text{(For SI)} \quad \text{SE-38}$$

$$M = 358.93\ (K\ Y\ d^2\ Fa)\ (\ D\ hw\ )^{(1/2)} \quad \text{(For Customary)}$$

$$Q = 0.01252\ (K\ Y\ d^2\ Fa)\ \left(\frac{hw}{D}\right)^{(1/2)} \quad \text{(For SI)} \quad \text{SE-39}$$

$$Q = 358.93\ (K\ Y\ d^2\ Fa)\ \left(\frac{hw}{D}\right)^{(1/2)} \quad \text{(For Customary)}$$

Symbols:

B = ratio of d to pipe inside diameter, dimensionless
C = coefficient of discharge, dimensionless, look up in orifice, nozzle, or venturi tables
D = density of fluid at primary element, $kg/m^3$ ($lb/ft^3$)
d = diameter of orifice, nozzle throat, or venturi throat, mm (in.)
Fa = area factor for thermal expansion of primary element, dimensionless, look up in orifice, nozzle, or venturi charts
hw = differential pressure of taps, mm (in.) of water
K = flow coefficient, dimensionless, look up in orifice, nozzle, or venturi tables
M = mass flow rate, kg/h (lb/h)
Q = volume flow rate, $m^3/h$ (ft3/h)
Y = fluid expansion factor, dimensionless, look up in charts

4.2 Positive displacement meter, turbine meter, and vortex shedding meter.

$$M = 3600\ (D)\ (f\ /\ K) \quad \text{SE-40}$$

$$Q = f\ /\ K \quad \text{(For SI)} \quad \text{SE-41}$$

$$Q = 60\ (f\ /\ K) \quad \text{(For Customary)}$$

Symbols:

$D$ = density of fluid, $kg/m^3$ (lb/gal)
$M$ = mass flow rate, kg/h (lb/h)
$Q$ = volume flow rate, $m^3/s$ (gpm)
$f$ = pulse frequency, Hz
$K$ = calibration factor, pulse/$m^3$ (pulse/gal)

4.3 Variable area flow meter.

$$M = K\ a\ D_w \left(\frac{Vf \times Gf\ (G_f - G)}{A_f}\right)^{1/2} \qquad \text{SE-42}$$

When measuring liquid refrigerant flow, the meter should be calibrated for the refrigerant at its flowing temperature. If the meter is calibrated for water, the specific gravity of the refrigerant should be used to adjust the measured flow rate by:

$$M_{ref} = M_{water}\ (\ G\ )^{(1/2)} \qquad \text{SE-43}$$

Symbols:
$a$ = annular area of flow, $m^2$ ($ft^2$)
$D_w$ = density of water, $kg/m^3$ ($lb/^3$)
$G$ = specific gravity of fluid
$G_f$ = specific gravity of float
$GF$ = gravitational force of float, grams
$K$ = flow constant
$M$ = mass flow rate, kg/s (lb/h)
$M_{ref}$ = flow rate of refrigerant, $kg/m^3$ ($lb/ft^3$)
$M_{water}$ = meter reading calibrated for water, $kg/m^3$ ($lb/ft^3$)
$V_f$ = volume of float

## 5. Electric power. (Horsepower equations are for customary unit use only)

5.1 Single phase.

To calculate from measured wattage input.

$$HP = \frac{\text{Watt input}}{746} \qquad \text{SE-44}$$

To calculate from measured voltage, current and power factor. The motor efficiency must be estimated.

$$HP = \frac{I \times E \times Eff \times Pf}{746} \qquad \text{SE-45}$$

5.2 Three phase. To calculate from watt meter measurement as given in SE-45, or from measured voltage, current, and power factor. Efficiency of motor must be estimated.

$$HP = \frac{1.73 \times I \times E \times Eff \times Pf}{746} \qquad \text{SE-46}$$

where

E is the line potential, volts
Eff is the motor efficiency, %
Pf is the motor power factor, %
HP is motor horsepower, hp
I is the measured current, A

## EXHIBIT 2-C STANDARD TEST PROCEDURES

**1. General.** Standard test procedures which are used frequently are described in this EXHIBIT. They are referenced within various chapters of this guide.

**2. Reference standards.**

a. ASHRAE Standard 41.1 (Standard Measurements Guide: Section on Temperature Measurements) describes instruments, measurement techniques, and recommended practices for temperature measurement generally encountered in HVAC equipment testing. The temperature range is limited between 4.4 to 204.4 °C (40 to 400 °F). The instruments covered are mercury-in-glass thermometers, thermocouples, and resistance thermometers.

b. ASHRAE Standard 41.5 (Standard Measurement Guide: Engineering Analysis of Experimental Data) describes definitions, recommended practices and procedures for treating and reporting test data. Uncertainty analyses of test data are discussed.

c. ASHRAE Standard 41.6 (Standard Method for Measurement of Moist Air Properties) describes instruments, measurement techniques, and recommended practices for measuring air humidity. It gives recommended calculation procedures of moist air properties. Instruments included are psychrometer, dew point hygrometer, heated electrical salt-phase transition hygrometer, Dunmore sensor, and electrolytic hygrometer.

d. ASHRAE Standard 41.7 (Standard Method for Measurement of Flow of Gas) describes meter construction, measurement techniques, and recommended practices for measurement of gas flow by orifice meter. Flow formulae are given.

e. ASHRAE Standard 41.8 (Standard Methods of Measurement of Flow of Fluids--Liquids) is similar to the standard in d. above. This Standard is for liquid flow measurement.

f. ASHRAE Standard 111-1988 (Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air Conditioning and Refrigeration Systems)

g. ASME PTC 19.3 (Temperature Measurement Instruments and Apparatus) describes various temperature measurement instruments and recommended measurement practices. Calibration methods of temperature instruments is also given.

h. ASME PTC 19.5 (Flow Measurement Instruments and Apparatus) deals with flow measurement and is similar in purpose to the standard in f. above.

i. ISA MC-96.1 (Standard for Temperature Measurement Thermocouples) describes principles and recommended practices of temperature measurement of thermocouples.

**3. Permanently installed sensor locations.** It is extremely important that permanently installed field sensors as part of the contract be located and installed correctly, even if site conditions make it difficult. A case in point is the locations of primary elements for water flow rate measurements (such as orifice plates). It is extremely difficult, if not impossible, to get good test results during commissioning, if the primary element is installed at a poor location for a large pipe. Good installation practices as recommended by various engineering guide books (e.g. ASHRAE standards) should be followed.

## 4. Simulation of sensors.

4.1 Reasons for simulating sensors. At the time of commissioning, a sensor responds to only one condition of the controlled variable where the sensor is situated. Therefore only one response of the control loop may be observed. It is desirable to vary the controlled variable so that more than one or a continuous set of responses may be tested. In most cases, it is not practical to subject the sensor to the full range of possible changes. However, a simulated change may be easily and accurately accomplished.

4.2 Principal of simulation. Responding to the controlled variable, a sensor varies the output signal (pneumatic pressure, electric resistance or voltage, etc.) transmitting to the controller at a predetermined relationship. If this relationship is known, the sensor may be bypassed and an appropriate signal fed into the controller to represent the controlled variable condition.

4.3 Preparation. There are numerous kinds of sensors used in detecting different controlled variables in a project. The commissioning team must be familiar with the project specifications and especially the submittals before inspections and tests. The simulation procedures described in this guide are the ones most commonly encountered.

4.4 Sensor simulation procedures.

4.4.1 Temperature, STP-1.

4.4.1.1 Pneumatic control system.

* Obtain a temperature/air pressure relationship chart of

the sensor from the contractor.

* Disconnect the sensor tubing at the controller and replace with the output tubing of a portable pneumatic calibrator (simulator). The building compressed air source for the control system or manual pressure generator may be used for the calibrator.

* Manipulate the pressure output of the calibrator. This output corresponds to a desired temperature simulation.

* Observe and record the responses of the equipment or system.

* After test, restore the sensor pneumatic tube to the controller after test. Make sure no leakage occurs afterward.

4.4.1.2 Electric/electronic control system.

* Depending on the type of temperature sensing devices installed, obtain a temperature/resistance, temperature/voltage, or temperature/current chart. Note that not all temperature sensors of the same type have the same charts.

* Disconnect the output wires of the sensor at the transmitter and connect a resistance simulator (for RTD or thermistor type sensor) or a thermocouple simulator (for thermocouple type sensor).

* Manipulate the resistance or the voltage simulator according to the charts to simulate the desired temperature.

* Observe and record the responses of the equipment or system.

* Restore the original wires to the transmitter after test.

4.4.2 Humidity, STP-2.

4.4.2.1 Pneumatic system. Similar to the procedure outlined in paragraph 4.4.1.1 above, except that a humidity/air pressure chart is used.

4.4.2.2 Electric/electronic. Similar to the procedures outlined in paragraph 4.4.1.2 above, except that humidity/resistance, humidity/voltage, or humidity/current charts are used.

4.4.3 Air static pressure, STP-3.

4.4.3.1 Connect the pressure calibrator to the pressure sensor of the system to be tested. Generate a gage or differential pressure as outlined below.

4.4.3.2 The pneumatic calibrator (simulator) may be connected to a steady air pressure source.

4.4.3.3 Manipulate the pressure calibrator to generate the desired pressure output.

4.4.3.4 Observe and record the responses of the equipment or system.

4.4.4 Fluid flow, STP-4. Applies in testing of monitoring and controlling of air, water, and steam systems to simulate different flow rates.

4.4.4.1 Disconnect sensing lines from the primary sensing element to the unit receiving the sensed signal. Examples are:

* water sensing lines from orifice plate to transmitter;

* air sensing lines from pitot rake assembly to transmitter;

* electric signal lines from pulse generating meters (e.g. turbine meter, vortex shedding meter) to pulse counter.

4.4.4.2 Connect signal simulator to the project signal receiving unit. Examples of signal simulators are:

* water manometer;

* air pressure calibrator;

* count generator.

## 5. Measurement of air flow rate in duct, STP-5.

5.1 Select a location which is at least 7.5 diameters downstream from any fitting which may cause air disturbance or a location at least 1.5 diameters downstream from straightening vanes for pitot traverse.

5.2 For round ducts divide the duct cross sectional area into at least 5 annular rings of equal area. Take 4 velocity pressure readings with pitot tube in each ring along two diameters of the duct at right angles. Measured from the center of the duct, pitot measurement positions are 0.316r, 0.548r, 0.707r, 0.837r, and 0.949r, where r is the radius of the duct.

5.3 For rectangular ducts divide the duct cross sectional area into at least 16 sub-rectangles of equal area. Take one velocity pressure reading with pitot tube at the center of each sub-rectangle.

5.4 If velocity pressure readings fluctuate the average of several readings should be used for each measuring point.

5.5 Calculate individual air velocity from each measured velocity pressure by using SE-10 or SE-11.

5.6 Average individual velocities to obtain the averaged duct air velocity.

5.7 Calculate volume flow rate of air by using SE-13.

5.8 Test work sheets for air flow rate measurement in round and rectangular duct, WS 2C-1 and WS 2C-2, are included in the appendix.

## 6. Measurement of air flow rate across coil or filter face, STP-6.

6.1 Select a face downstream of coil or air filter. The sole selection criterion is steady air flow with minimum air turbulence caused by obstructions.

6.2 Divide the coil or filter face into at least 16 sub-areas with the maximum sub-area not more than one square foot.

6.3 Measure air velocity at the center of each sub-area. The instrument used for the velocity measurement should be appropriate for the velocity being measured. The instrument should be held perpendicular to the face of the coil or filter. If the measurement is in a built-up casing, the tester's body should not be allowed to interfere with the reading being taken.

6.4 Average individual velocities to obtain the averaged duct air velocity.

6.5 Calculate volume flow rate of air by using SE-13.

6.6 Same test work sheets for rectangular ducts may be used for measuring at coils or at air filters.

6.7 Accuracy is considerably less than the results of pitot tube measurement in ducts. Recommend to be used only when duct measurement is not practical.

# CHAPTER 3 REFRIGERATION PLANT

1. **Scope.** This chapter provides inspection and testing procedures for refrigeration systems and associated heat rejection equipment. Refrigeration machines included in this Chapter are centrifugal, absorption, and reciprocating types. Heat rejection equipment includes cooling towers, air cooled and evaporatively cooled refrigerant condensers.

## 2. Reference Standards.

a. ASHRAE Standard 15 - Safety Code for Mechanical Refrigeration.

b. ASHRAE Standard 20 - Methods of Testing for Rating Remote Mechanical-Draft Air-Cooled Refrigerant Condensers.

c. ASHRAE Standard 30 - Method of Testing Liquid Chilling Packages.

d. ASHRAE Standard 64 - Methods of Testing Remote Mechanical-Draft Evaporative Refrigerant Condensers.

e. ASHRAE Standard 90 - Energy Conservation in New Building Design.

f. ARI Standard 460 - Remote Mechanical Draft Air-Cooled Refrigerant Condensers.

g. ARI Standard 550 - Standard for Centrifugal or Rotary Water-Chilling Packages.

h. ARI Standard 560 - Standard for Absorption Water-Chilling Packages.

i. ARI Standard 590 - Standard for Reciprocating Water-Chilling Packages.

j. ASME Standard PTC-23 - Test Code for Atmospheric Water-Cooling Equipment.

k. CTI Bulletin ATC-105 - Acceptance Test Code for Water Cooling Towers.

## 3. Refrigeration System Inspection.

3.1 Refrigeration machines and components shall be inspected for their construction and installation to meet safety and functional requirements. See EXHIBIT 3-A for inspection procedures. See Appendix for inspection check lists.

3.2 Heat rejection equipment and components shall be inspected for their construction and installation to meet safety and functional requirements. See EXHIBIT 3-B for inspection procedures. See Appendix for inspection check lists.

## 4. Refrigeration System Testing.

4.1 Equipment Testing General. Refrigeration machines and heat rejection equipment, shall be tested for full load capacity, full and part load performances, control sequencing, and safety protection. Startup and operating tests are included.

4.2 False Load. If building load at the time of testing does not correspond to the specified capacity design conditions and/or commissioning tests, a false load shall be introduced to make up for the building load shortage. Precautions must be taken so that the introduction of false loads do not damage the refrigeration equipment or any other building equipment, nor cause excessively uncomfortable conditions in the building. See test procedure appendices for options and procedures of applying false load.

4.3 Equipment Operation Prior to Test. If the refrigerating system has been in operation for more than 80 hours, the heat exchanger surface of the refrigeration machine should be cleaned before testing to meet the fouling factors specified. However, since scaled tubes may cause tests to fail, the burden of determining tube cleaning rests on the construction contractor and the chiller manufacturer.

4.4 Manufacturer's Factory Testing. The project specification may allow manufacturer's factory testing in lieu of field testing. Factory testing must be witnessed by selected members of the commissioning team. The test intention, test procedures, and acceptance criteria of this guide must be followed.

4.5 Centrifugal Refrigeration Machine Testing. See EXHIBIT 3-C for test procedures.

4.6 Reciprocating Refrigeration Machine Testing. See EXHIBIT 3-D for test procedures.

4.7 Absorption Refrigeration Machine Testing. See EXHIBIT 3-E for test procedures.

4.8 Heat Rejection Equipment Testing. See EXHIBIT 3-F for test procedures.

4.9 See Appendix for test work sheets.

## EXHIBIT 3-A INSPECTION PROCEDURES FOR REFRIGERATION MACHINES

### 1. General.

1.1 Review equipment manufacturer's instructions on start-up and operation procedures.

1.2 Give general inspection of refrigeration machine and associated equipment, including base, vibration eliminating units, starting electrical equipment, piping, etc. Be sure that no damage or rusting occurred.

1.3 Check equipment name plates to verify equipment model. Compressor, condenser, evaporator, and starter must have the same model numbers as approved submittals.

1.4 Check for headrooms and access spaces around the machine. The spaces required in the design documents must be provided. Pay special attention to the refrigeration machine heat exchanger tube replacement and cleaning spaces.

1.5 Verify installed pipe fittings and accessary equipment against project drawings for completeness and proper installation. Fittings and accessories include but not limit to valves, strainers, vibration elimination units, thermometer wells, piping supports, etc.

1.6 Verify field installed wiring against project drawings and manufacturer's submittals.

1.7 Check piping at equipment connections. Pipes should be supported from building structure without undue stress on equipment (refrigeration machine, pump, etc.).

1.8 Check refrigerant relief pipe installation in accordance to project drawings. If drawings do not indicate, all discharge pipes must terminate at outside of building 4.6 m (15 ft) minimum from ground or 6.1 m (20 ft) minimum from windows or doors. Pipe size must not be smaller than relief device opening area.

1.9 Check water flow direction marks for check valves and flow switches.

1.10 All moving parts (motors, belts, etc.) should have protection shields for personnel safety.

1.11 Check alignment for all non-hermetic motor driven equipment (solution and refrigerant pumps of absorption machines are usually hermetic type), including motor, compressor, gear boxes, oil pump, purge pump, and water pumps. Using some simple tools such as straight edges, square edges, plumb lines, and strings yield good results. Also observe shaft and coupling for misalignment while machine is running.

1.12 Observe belt tightness of belt driven equipment. Use belt tension gage if needed. Belt tension should be as recommended by belt manufacturer.

1.13 Check for completeness of required instrumentation, including thermometers, gages, temperature and flow measuring and control devices. Required straight pipe runs and arrangements for temperature and flow measuring devices must be met.

1.14 Check electric equipment and controls for proper grounding.

1.15 Check all electrical connections for tightness.

1.16 For motor starter equipped with overcurrent heaters, check heater sizes against starter manufacturer's recommendations. The recommendations are usually contained in operator's manual or posted in starter cabinet.

1.17 If pneumatic pressure is used for system controls, check control air system pressure.

1.18 Be sure the machine is charged with right kind of refrigerant. Check sight glass for proper level.

1.19 Check for refrigerant leakage at component connections, shaft seals, refrigeration pipe joints, and valves with electronic halogen leak detector. The equipment room should be well ventilated to increase the sensitivity of detection.

1.20 Make certain that the lubrication material used satisfy the manufacturer's recommendations. Lubrication are required for compressor bearings, motor bearings, gear trains, and other equipment. Oil level must be as recommended.

1.21 Check thermal insulation for damages and omissions.

1.22 Check surface paint for damages and omissions. Equipment nameplates must not be painted over. Required equipment labels must be present and legible.

1.23 No leakage should be noted for water, oil, refrigerant, steam, and other fluid (such as lithium bromide).

1.24 Check vibration elimination units. The chiller or its sub-base should float freely on springs or resilient pads without solid objects transmitting vibration from chiller to base.

1.25 Note any unusual noise and vibration at varying load conditions.

## 2. Centrifugal refrigeration machine.

2.1 Inspect alignment at points of connections for field assembled machines (see paragraph 1.11 above for alignment tools).

2.2 Be sure that temperature and pressure indicators for oil system are functioning properly to indicate the oil system operation.

2.3 Regardless of the oil pump arrangement, the oil pressure supplied to the compressor bearings and gear box must meet the minimum pressure requirement specified by the manufacturer whenever the compressor is running (including coastdown). If a separate oil pump is used for start-up only, observe the switch-over operation of the start-up pump and the main oil pump to insure proper oil pressure at all times.

2.4 Check compressor interlocking function with oil pressure to insure the operation of paragraph 2.2 above.

2.5 Be sure oil pump is wired separately from circuit feeding to the compressor.

2.6 Be sure oil filter is properly installed in oil pumping system and it is clean.

2.7 Check oil heating system for proper operation. Oil sump temperature must not be lower than the manufacturer's recommended temperature for proper separation of refrigerant. Be sure the oil temperature control system is operating properly.

2.8 Check oil cooling system for proper oil temperature control and operation. Oil temperature shall not be over the manufacturer's recommended temperature.

2.9 Be sure necessary piping accessories (valves, strainers, etc.) are installed in oil cooling system cooling water lines.

2.10 Observe compressor pre-rotation damper operation for the entire capacity range. The damper control system (actuator and linkage) should have smooth operation without fluttering.

2.11 Be sure compressor pre-rotation dampers do not open before compressor reaches full speed.

2.12 Note unusual noise and vibration of compressor, bearings, gear box, and motor.

## 3. Absorption refrigeration machine.

3.1 Absorption refrigeration machines are sensitive to capacity control at low condensing water temperature. Control line pneumatic pressure, steam valve, water thermometer and 3-way condenser water valve need to be checked for proper calibration.

3.2 Check pump lubricant (usually water or salt solution) system strainer and magnetic strainer for cleanliness.

3.3 Check strainers and traps for steam and hot water supply lines for cleanliness, and condensate piping for proper type of steam traps and vacuum breakers. Check for proper placement and orientation of same.

3.4 Cleaning of condenser tubes due to fouling is more important for absorption chillers than other types of chillers because of higher condenser water temperature of absorption chillers. The Team should note the time length of the chiller in operation prior to the time of inspection and signs of fouling. If fouling is suspected, a decision of cleaning condenser tubes should be made with the construction contractor and chiller manufacturer's representative.

3.5 At the time of commissioning inspection, the chiller should have been adjusted and charged properly by manufacturer's representative. The Team shall obtain charge data sheet (lithium bromide and additives). If solution samples have not been drawn for concentration tests, samples should be gathered when the chiller is in operation (see EXHIBIT 3-E).

3.6 Check relief pipe installation for chiller pressure relief device in accordance to project drawings. If drawings do not indicate, relief pipe from steam chiller must terminate at outside of building and relief pipe from hot water chiller must terminate at a floor drain. Pipe size must not be smaller than relief device opening area.

## 4. Reciprocating refrigeration machine.

4.1 Be sure that temperature and pressure indicators for oil system are functioning properly to indicate the oil system operation. Oil pressure must be as recommended by the manufacturer.

4.2 Check compressor interlocking function with oil pressure to insure the operation of paragraph 4.1 above.

4.3 Be sure oil pump is wired separately from circuit feeding to the compressor.

4.4 Be sure oil filter is properly installed and clean.

4.5 Check oil heating system for proper operation. Electric wiring should be verified as per manufacturer's submittals or checked to be sure that crankcase heater power is on even when the main power is off. The crankcase heater should be installed snugly in its position. It should be on during compressor off time.

4.6 Check oil level before and during operation. Oil should not be foaming excessively.

4.7 For chillers with remote condensers, check refrigerant pipe pitch and oil traps for proper oil return.

4.8 For air cooled and evaporatively cooled chillers, spaces for air circulation is important. Be sure that manufacturer's recommendations are followed and air is not short circulated from discharge to intake.

4.9 Check direction of fan rotation for air cooled condenser.

4.10 For air cooled condensers equipped with damper controls for low ambient operation, check damper mechanism for proper adjustment and operation.

4.11 Check direction of fan rotation for evaporative condenser.

4.12 Check water level of evaporative condenser. Water float valve shall not "chatter". Spray nozzles should have correct pattern without blockage. There shall be no excessive water carry-through.

4.13 If evaporative condenser is specified and equipped with bleed-off arrangement, visually check valve adjustment for flow.

4.14 Check electric interlocks with condenser water pump and chilled water pump. Check operation of flow switches.

## 5. Brush cleaning system for refrigeration machine.

5.1 This inspection procedures apply to refrigeration machines equipped with automatic or manually initiated, built-in brush cleaning system for cleaning condenser tubes. Consult project specifications for required specific features of the tube cleaning system.

5.2 Visually inspect installed components. They may include manual valves, flow diverting valve, pneumatic valve actuator, solenoid valve, timer for cycle control, manual override, indicating lights for power and diverting valve positions, diverting valve speed control and indicator, cleaning cycle counter, flow switch bypass, alarms, and control panel.

5.3 Check the function of manual override for actuating the cleaning action.

5.4 Check diverting valve actuation speed to meet the limitations of the manufacturer's recommendations. Be sure the speed adjustment setting is secured.

5.5 Observe water flow and brush cleaning action for both forward and reverse travels. Indicating lights and diverting valve action should agree.

5.6 The time between forward and reverse cleaning actions should be as recommended by manufacturer.

5.7 Manually initiate cleaning action at least three times to ensure proper operation.

5.8 Observe timer function. Timer should be set to actuate cleaning action at desired intervals and time. Avoid setting time for cleaning condenser tubes at high cooling load hours.

5.9 For manually operated systems, be sure the operation of shut-off valves and/or diverting valve will not cause water hammer damage.

5.10 Check cleaning cycle counter for proper counting.

5.11 Be sure proper lubrication is applied to flow diverting valve and valve actuator.

5.12 Record inspection data and final settings.

5.13 See EXHIBIT 3-C for leaking test of flow diverting valve.

# EXHIBIT 3-B INSPECTION PROCEDURES FOR HEAT REJECTION EQUIPMENT

## 1. General.

1.1 Review equipment manufacturer's instructions on start-up, operation and maintenance procedures.

1.2 Give general inspection of heat rejection equipment and its associated equipment, including base, vibration eliminating units, starting electrical equipment, piping, valves, etc. Be sure that no damage occurred during construction.

1.3 Check equipment name plates to verify equipment model. Cooling tower, heat exchanger, and their auxiliary equipment must have the same model numbers as approved submittals.

1.4 Check for clearance space, access doors, ladders, lightening protection, grates, and guard rails for completeness. Manufacturer's recommended access spaces must be provided. There shall be no obvious obstruction to air circulation.

1.5 Verify installed piping and accessary equipment against project drawings for completeness and proper installation. Pipe fittings and accessories include but not limit to valves, strainers, vibration elimination units, thermometer wells, pressure gages, piping supports, etc.

1.6 Verify installed wiring against project drawings.

1.7 Check piping at equipment connections. Pipes should be supported from building or ground support unless project drawings or approved submittals allow supporting on cooling tower.

1.8 Check fluid flow direction marks for check valves and flow control valves.

1.9 All moving parts (motors, belts, etc.) should have protection shields for personnel safety.

1.10 Check alignment for all motor driven equipment, including motor, gear boxes, fans and water pumps. Using some simple tools such as straight edges, square edges, plumb lines, and strings yield good results. Also observe shaft and coupling for misalignment while machine is running.

1.11 Observe belt tightness. Use belt tension gage if needed. Belt tension should be as recommended by belt manufacturer.

1.12 Check for completeness of required instrumentation, including thermometers, gages, temperature and flow measuring and control devices. Required straight pipe runs and arrangements for temperature and flow measuring devices must be met.

1.13 Check electric equipment and controls for proper grounding.

1.14 Check all electrical connections for tightness.

1.15 Make sure that fan motor is of the type as specified.

1.16 For motor starter equipped with overcurrent heaters, check heater sizes with starter manufacturer's recommendations. The recommendations are usually contained in operator's manual or posted in starter cabinet.

1.17 If pneumatic pressure is used for system controls, check control air system pressure.

1.18 Make certain that the lubrication material used satisfy the manufacturer's recommendations. Lubrication are required for fan bearings, motor bearings, gear trains, and other equipment. Oil level must be as recommended. External extended grease lines must be provided if specified.

1.19 Check thermal insulation for damages and omissions (for cooling tower winterizing auxiliaries, if required in specifications).

1.20 Check surface paint for damages and omissions. Equipment nameplates must not be painted over. Required equipment labels must be present and legible.

1.21 Check vibration elimination units. Equipment should float freely on springs or resilient pads without solid objects transmitting vibration from equipment to building.

1.22 If winterizing equipment is specified, they shall be inspected and checked in according to the specifications.

1.23 Observe correct direction of fan rotation.

1.24 Note any unusual noise and vibration.

## 2. Cooling tower and evaporative condenser.

2.1 Inspect water basin for cleanliness.

2.2 Verify overflow and drain pipes (Drains are usually specified to be piped to sewer). Check for outlet basin screen, if specified.

2.3 Water should not spill over hot water basins and cold water collection basin during any time of the operation. There should not be excessive splash over air inlet or excessive carryover from air discharge.

2.4 Observe makeup valve and float mechanism for proper operation. Water level of the cold water collection basin should as recommended by the manufacturer. For equipment specified with constant bleeding, observe the amount of makeup to be approximately correct.

2.5 Observe water distribution orifices for blockage.

2.6 For equipment with spray nozzles, turn fan off (condenser water pump is on) and observe nozzle spray pattern and blockage.

2.7 For cooling towers having more than one cell, observe water distribution pattern for obvious imbalance of balancing valves or distribution valves. Water level in hot water basins should be as recommended by the manufacturer.

2.8 For field assembled towers, check material (fill, frame, casing, baffle, water distributing plate, etc.) and installation against specifications and approved submittals.

2.9 Check cooling tower support structure with details shown on construction drawings or approved submittals to assure adequacy of support.

2.10 For tile filled towers, check tile supports against manufacturer's shop drawings.

2.11 Check that water treatment system is operational and adjusted. Check interlock of chemical pump with condenser water pump (or other interlock as specified).

## EXHIBIT 3-C CENTRIFUGAL REFRIGERATION MACHINE TEST PROCEDURES

**1. Scope.** The test procedures described in this EXHIBIT apply to packaged refrigeration machines using electric driven centrifugal compressors for refrigerant compression to achieve cooling effects. Electric motors may be open or hermetic types. The machines produce chilled water and their condensers are supplied with cooling water externally.

**2. Purpose.**

2.1 To verify full capacity of the installed refrigeration machine for meeting the specified capacity without exceeding the specified power input.

2.2 To verify part load power consumption of the machine not exceeding the specified part load power limits at the specified part loads.

2.3 To verify other limiting conditions set in the project specifications, such as maximum water side frictions of the heat exchangers.

2.4 To verify ability of cooling capacity control of the machine without encountering undesirable effects.

2.5 To verify operations of all components meeting their intended functions.

2.6 To verify safety operation of the machine.

**3. Industry standards.**

3.1 ARI Standard 550 (Standard for Centrifugal or Rotary WAter chilling Packages) prescribes requirements for testing of centrifugal refrigeration machines. It specifies the basis for testing, rating, and publishing of capacities and power requirements. Power input is measured for the compressor only. These machines are tested and rated under the following conditions:

| | |
|---|---|
| Leaving chilled water temperature | 6.7 °C (44 °F) |
| Chilled water flow rate | 0.043 L/s per kW (2.4 gpm/ton) |
| Entering condenser water temperature | 29.4 °C (85 °F) |
| Condenser water flow rate | 0.054 L/s per kW (3.0 gpm/ton) |
| Refrigerant side fouling factor | 0.0000 $m^2$ °C/W (.0000 hr $ft^2$ F/Btu) |
| Water side fouling factor | 0.000044 $m^2$ °C/W (0.0005 hr $ft^2$ F/Btu) |

3.2 Among other requirements, ARI Standard 550 lists the following required safety and operating controls:

Refrigerant high-pressure cutout
Freeze-protection cutout
Provision for interlocks to stop compressor operation upon failure of chilled water flow
Low oil-pressure cutout
Compressor over-speed trip (for non-electric motor drives)
Chilled water temperature controller
Compressor motor load limit control

3.3 ARI Standard 550 also requires that the water side of the evaporator and condenser be suitable for a working pressure of 1034 kPa (150 psig). Verify exact pressure rating required and installed.

3.4 ASHRAE Standard 30 (Methods of Testing Liquid Chilling Packages) describes methods of testing of liquid chilling refrigeration machines for their performance ratings. This standard does not specify the test conditions. Power measurement is for compressor driver and all auxiliaries.

3.5 ASHRAE Standard 15 (Safety Code for Mechanical Refrigeration) covers a much wider range of requirements than the refrigeration machine itself. Its purpose is to assure the safe design, construction, installation, operation, and inspection of refrigeration systems.

3.6 ASHARE Standard 90 (Energy Conservation in New Building Design) sets forth the requirements for the design of new buildings, including energy performance of HVAC equipment. The energy input to all auxiliary components of the refrigeration machine is included (consistent to ASHRAE Standard 30 requirements). See the latest edition for minimum performance requirements.

## 4. Preparation for test.

4.1 It is assumed that, before the scheduled test, the project contractor or manufacturer's representative has prepared the refrigeration machine in according to the recommendations of the manufacturer for startup and operation and an inspection of the refrigeration system by the Team has taken place (see EXHIBIT 3-A for inspection).

4.2 All measurement and test instruments must be calibrated before testing, unless documents can be shown satisfactorily that the instruments are in calibration (see Chapter 2 for calibration of instruments). Instruments supplied with the machine may be used to take test data after they have been calibrated and the accuracies satisfy the minimum tolerance requirements of tests.

4.3 In most cases, a false load is needed for full load performance test. Depending on individual project circumstances, false load may be introduced at the equipment room close to the refrigeration machine to be tested or to the building equipment installed as parts of the building facility (such as air handling systems). The former approach may require temporary equipment (such as temporary boiler or heat exchanger) to provide heat source, piping from the heat source to the refrigeration machine and/or cross-over piping between the condenser and the evaporator, and accessories such as shut-off valves and temperature controlling mixing valves. The Team should review the piping layout to be sure that water entering both evaporator and condenser may be adjusted individually to those of the specified values. The disadvantage of the latter approach is the long lagging time for the temperature at the refrigeration machine to stabilize (from the time to introducing false load at the air handling systems to achieve stable and desired conditions at the test machine). After it is determined the approach to take based on cost comparisons, good coordination between all involved parties is essential.

4.4 The heat exchanger tubes may not be clean to yield the specified fouling factors. Oil film needs to be cleaned when tubes are new. If the refrigeration machine has been running for some time to provide temporary cooling, the tubes should be cleaned before tests. This is especially important for condenser tubes, because of the low quality of the condenser water and higher temperature of the tube surface. It is difficult to measure the actual fouling factor or scale thickness in the field. Only actual cleaning will assure the correct performance of the machine. The Team should obtain a written statement from the contractor or witness the cleaning operation that the tubes are cleaned according to the manufacturer's recommendations (such as using chemicals). If the machine has been in operation, physical cleaning with rodded brushes may be necessary unless the refrigeration machine has automatic brush cleaning equipment and the frequency of cleaning has been set correctly since the refrigeration machine was in operation.

## 5. Recommended tests.

5.1 Full load test. The refrigeration machine must deliver the specified cooling capacity under the specified conditions. The specified conditions may be different from the basis of the manufacturer's published and selected conditions. The project specification usually also specifies the entering condenser water temperature, the leaving chilled water temperature, the condenser water and the chilled water flow rates, the maximum power consumption rate at these conditions, and the maximum water friction loss of the two heat exchangers. Each of these ratings or limitations must be verified by testing directly or verified by deducing from test data (see paragraph 7.3 for test procedures).

5.2 Part load test. Depending on the refrigeration machine's part load performance curve, the energy performance of a machine may vary considerably. In order to have optimum energy performance for the entire cooling season, several points of the performance curve may be specified to define a skeleton performance curve. The commonly specified points are at 75%, 50%, 25% of the full load, and/or the lowest desirable stable load. The test conditions for the part load may be different from those of the full capacity test conditions, depending on the specifications (see paragraph 7.4 for test procedures).

5.3 Capacity control test. With reduced load the machine should respond by reducing its capacity and vice versa. The test should verify the automatic capacity change following load changes without running into unstable conditions for the entire range of capacity from full load to minimum load as specified. Project specifications usually do not allow hot gas bypass above 10% of full load. Therefore, the test should also show the hot gas bypass operation to be compared with the specifications and the equipment manufacturer's claims (see paragraph 7.5 for test procedures).

5.4 Safety control test. To test the refrigeration machine's safety controls so that it will not be damaged during unforeseen events. In additions to the controls required in ARI Standard 550 (see paragraph 3.2, Industry Standards, of this EXHIBIT), all other safety control features should also be tested (see paragraph 7.1 for test procedures).

5.5 Auxiliary equipment operation test. Centrifugal refrigeration machine usually has oil pumping system, non-condensable purge system, and/or refrigerant pumpout system. Some refrigeration machines are specified with built-in brush cleaning system or separate add-on cleaning system. All these auxiliary systems shall be tested (see paragraph 7.2 for test procedures).

5.6 Cooling plant system test. This test involves interlocking of condenser pump, chilled water pump, cooling tower operation, and other cooling plant components, such as sequencing of chillers (see paragraph 7.6 for test procedures).

## 6. Instrumentation.

The required measurement, minimum accuracies, and measurement precautions are given below:

6.1 Temperature.

6.1.1 Chilled water temperature leaving evaporator. The measurement system error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.2 Direct measurement of temperature differential of the chilled water entering and the leaving evaporator. This measurement is preferred than deducing the difference from separate temperature measurements at the entering and the leaving chilled water, since it minimizes the errors of calibration of two temperature measurements. The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.3 Condenser water temperature entering condenser. Total measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.4 Direct measurement of temperature differential of the condenser water entering and the leaving condenser for the same reason as given for chilled water measurement. Same accuracy requirement as for chilled water, +/- 0.1 °C (0.2 °F).

6.1.5 The temperature sensor locations of these four measurements are important. They should be located to sense well mixed bulk water temperature. If chilled water or condenser water is used to cool any component of the refrigeration machine, the temperature sensors must be located to include the effects of this cooling.

6.1.6 The thermometers or temperature gages, supplied as integral parts of the refrigeration machine, such as for bearing, oil, refrigerant, etc., shall be calibrated to have errors less than +/- 0.6 °C (1 °F).

6.1.7 Temperature sensors and thermometers are usually installed in wells. They may be calibrated in laboratory or in field. Wells should be filled with thermal conducting compound to insure good thermal contact between the well and the sensing element.

6.1.8 If proper thermometer wells are not available, an insulated extension to a vent valve allowing water to flow continually across thermometer bulb may be used.

6.2 Water flow rate.

6.2.1 Chilled water pipe. The total error of combined sensing and readout devices shall not exceed +/- 3% of measured quantity.

6.2.2 Condenser water pipe. The total error of combined sensing and readout devices shall not exceed +/- 3% of measured quantity.

6.2.3 It is very important to check if the primary element location of the flow meters are appropriate. The minimum pipe lengths upstream and downstream of the primary element must be not less than those given in Chapter 2. Avoid areas where water flow may be swirl (e.g. after consecutive elbows). If space is tight provision for the use of flow straighteners is very helpful.

6.2.4 If chilled water or condenser water is used to cool any component of the refrigeration machine, the primary element of the flow meter must be located to include the effects of this flow.

6.2.5 In the majority of installations the water flow rate of centrifugal refrigeration machine does not vary. For a constant flow rate the type of flow meters to be used for permanent installation or just for commissioning tests can be easily selected. If differential pressure type (orifice plate or venturi, etc.) is used, the primary element with the largest throat diameter that still satisfies the required accuracy should be selected to minimize the friction loss associated with the measuring element.

6.3 Pressure instrument.

6.3.1 For differential pressure type primary element - water or mercury manometer, or electronic pressure readout unit. Manometers should read accurately to +/- 24.9 Pa (0.1 in. of water). Total error of primary element and readout unit shall not exceed +/- 3% of flow.

6.3.2 The pressure instruments supplied with the machine as a package, such as pressure gages for oil pressure and refrigerant pressure shall be calibrated in laboratory or in field. When these instruments are taken off the machine, exercise caution so that the media to be sensed shall not be in contact with the atmosphere.

6.3.3 Pressure gages are usually specified and installed at inlet and outlet of heat exchangers. These instruments may be used to verify the heat exchanger water pressure drops.

6.4 Energy measurement.

6.4.1 Polyphase watt meter or watthour meter. Error shall not exceed +/- 0.5% of reading.

6.4.2 Measurement of energy shall include that consumed by compressor and auxiliaries. This requirement differs from that of ARI Standard 550.

6.4.3 Check and record electric voltage between feeders and the frequency at the power supply.

**7. Test procedures.** Refrigeration machine manufacturers usually have detailed check out procedures after field installation for their particular models. The following test procedures are designed to be generic and should be used as guidelines only. Since the test agent is responsible for performing tests and for demonstrating meeting construction documents, the Team must examine all details of installation and operation manuals provided by the manufacturer and coordinate with the testing agent to modify the test procedures given in this guide. However, the intended purpose of these test must be carried out and their acceptance criteria must be satisfied.

7.1 Safety control test. This test should be performed before other tests after an inspection. Some situations requiring pressure and temperature to trigger control actions are not appropriate to test on line. Therefore these tests are limited to checking safety control circuits with simulated controlled variables. In some cases (refrigerant pressure, oil pressure, etc.), they are tested indirectly without creating simulated controlled variables (pressure). Indicating lights, relays, actuators, and controlled components of the machine are used to confirm the control action.

7.1.1 Make sure area is clear of personnel. - IMPORTANT!

7.1.2 Check voltage balance of electric power service. The maximum voltage deviation from average of three voltage measurements should not be greater than +/- 1% of the average. In equation form, it is:

$$\%\ \text{voltage imbalance} = \frac{(A,\ B,\ \text{or}\ C) - (A + B + C) / 3}{(A + B + C) / 3}$$

where A, B, and C are voltage measurements between phases.

7.1.3 Disconnecting electric power to the compressor is the next step. Depends on the wiring configuration, the power leads to the compressor may have to be physically disconnected. Do not rely on automatic wiring arrangement for disconnecting compressor.

7.1.4 Connect power to control circuits and auxiliary equipment circuits. Control circuit usually have separate disconnect.

7.1.5 Test all pilot lights and alarms by pressing the appropriate buttons.

7.1.6 Simulate compressor running by turning on the compressor switch. Indicating light for compressor should show "on".

7.1.7 At this stage of testing, all temperature and pressure indicators should have been calibrated already.

7.1.8 Test temperature actuated safety controls. Set temperature bath to the trip temperature of the control as recommended by the refrigeration manufacturer. Remove temperature sensors from wells and place in temperature bath. Vary the bath temperature +/- 1.1 °C (2 °F) slowly. By observing the pilot lights, the make and break points of the chiller circuits shall be recorded. Also record the set point of the temperature switch. The tolerance of the set point and the actual break point shall not exceed 0.6 °C (1 °F). The temperature switches to be tested shall include, but not limited to, the following:

7.1.8.1 Refrigerant low temperature cutout.

7.1.8.2 Refrigerant high temperature cutout.

7.1.8.3 Chilled water low temperature cutout.

7.1.8.4 Oil heater thermostat control.

7.1.9 Test pressure actuated safety controls. For safety reasons pressure actuated safety switches are not provided with valves to be isolated from the chiller. Pressure gages (already calibrated) located at the switch sensing areas can be used indirectly to check the functions of these switches. Move the switch setting slowly up above the manufacturer's recommended pressure and observe the pilot lights. Do likewise while moving the setting down slowly. Record the pressure (as indicated by the pressure gage) where it trips the compressor running circuit. The tolerance of the recommended and actual tripping pressures shall not exceed +/- 3% of recommended values. Pressure switches to be tested shall include, but not limited to, the following:

7.1.9.1 Condenser high pressure cutout.

7.1.9.2 Evaporator low pressure cutout.

7.1.9.3 Low oil pressure cutout.

7.1.10 Test flow actuated safety controls. Bypass the flow switches of evaporator and condenser water at the switches by using jumper wires and observe pilot lights. This does not indicate the functioning of the flow sensing mechanism which will be verified later in full load test.

7.1.11 Reconnect motor wires. Be sure to observe safety procedures.

7.1.12 Data to be recorded (Not all items are required for the same machine. See project specification and submittals for items required and installed):

7.1.12.1 Mechanical equipment room temperature.

7.1.12.2 Cutin and cutout temperature of refrigerant low and high temperature safety.

7.1.12.3 Cutin and cutout temperature of chilled water low temperature control.

7.1.12.4 cutin and cutout temperature of oil heater thermostat.

7.1.12.5 Cutin and cutout pressure of condenser high pressure safety.

7.1.12.6 Cutin and cutout pressure of evaporator low pressure safety.

7.1.12.7 Cutin and cutout pressure of oil pressure safety.

7.1.12.8 Operation of chilled water and condenser water flow switches.

7.2 Auxiliary equipment test. This test should be performed after the cooling tower water circuit has been tested, adjusted and balanced.

7.2.1 Start condenser water pump. Check pump amperage for possible overload.

7.2.2 Check condenser water flow rate. This should be done after cooling tower is readied for operation. The installed condenser water pump (permanent or temporary) may not give the correct flow rate. If the flow rate differs from that of the specified rate, adjust flow balancing device on condenser water line to the required rate.

7.2.3 Check temperature of entering condenser water. The cooling tower temperature control should be adjusted to provide the desired condenser entering water temperature.

7.2.4 Start chilled water pump. Check pump amperage for possible overload.

7.2.5 Check chilled water flow rate. Adjust flow balancing device if necessary.

7.2.6 Although the following items may have been checked during inspection at the beginning of the functional performance testing, they shall be checked again for running tests as routine startup procedure.

7.2.6.1 If pneumatic control is used, check air supply system.

7.2.6.2 Check oil and refrigerant levels.

7.2.6.3 Check oil sump temperature. The manufacturer's recommended oil temperature should be maintained for at least 24 hours or the duration as recommended by the manufacturer. The oil temperature control thermostat is tested in the previous paragraph. This step confirms the entire oil heater function.

7.2.7 If temporary cross-over piping connections are used for providing false load, adjust flow control valves on cross-over piping to give both condenser and chilled water the correct flow rate.

7.2.8 Test oil system.

7.2.8.1 Be sure cooling water is supplied to the oil cooling system.

7.2.8.2 Be sure oil filter is clean (should have been checked during inspection).

7.2.8.3 Turn on oil pump.

7.2.8.4 Record oil pressure. Record temperature at sump, oil cooler, and compressor bearing. The manufacturer's pressure requirements must be met.

7.2.8.5 Oil pressure during coastdown is tested later in part load test.

7.2.9 Test automatic purge system by switching controls to manual position. Manufacturer's recommended test procedures should be followed.

7.2.10 Test refrigerant pumpout system by following manufacturer's recommended procedures. If a reciprocating machine is specified and installed for the pumpout system, it shall be switched on for at least half hour and the following data recorded:

7.2.10.1 Discharge pressure.

7.2.10.2 Suction pressure or temperature.

7.2.10.3 Oil pressure.

7.2.10.4 Condenser water entering and leaving temperature.

7.2.11 Test condenser brush cleaning system. The inspection procedures for condenser brush cleaning system are given in EXHIBIT 3-A. In the inspection procedure, most of the functional testing of the system, such as for manual override to initiate operation, checking of diverting valve actuation speed, timer action between forward and reverse cleaning, counter operation, etc., have been performed. During auxiliary equipment test the diverting valve should be tested to be certain that the valve is not leaking condenser water from supply pipe to return pipe. This is especially important during normal mode of operation of the condenser (brush cleaning system not in operation).

7.2.11.1 Attach two 0.025 m (1 inch) thick, 0.15 m by 0.15 m (6 in. by 6 in.) minimum size mineral wool thermal insulation on condenser water return pipe (water leaving condenser) at locations on both sides of the flow diverting valve approximately 0.30 m (3 feet) from the valve. This is to minimize the influence of ambient air on pipe surface temperature measurement.

7.2.11.2 Insert temperature sensor of a portable digital thermometer under the insulation covers and take temperature alternately between these two locations with the same thermometer. Take three sets of temperature readings (a total of six readings). Five minutes should be allowed between insertion of sensor and temperature taking for each reading. The time to perform this test should be when the refrigeration machine is close to fully loaded and the refrigeration machine is running at approximately stable conditions.

7.2.11.3 The temperature difference between the averaged three readings of the same locations shall not be greater than 0.5 F.

7.3 Full load test. This test follows auxiliary equipment tests with chilled water and condenser water pumps in operation.

7.3.1 Set chilled water supply temperature setting to the specified full load supply temperature.

7.3.2 Start the refrigeration machine.

7.3.3 Observe the rotation direction of motor and compressor to be correct.

7.3.4 The running of compressor proves that the evaporator water and condenser water flow switches are functioning (see previous description on safety tests).

7.3.5 Load the machine by following manufacturer's recommendations.

7.3.6 With constant flow rate, the temperature differential of the evaporator indicates the loading condition of the refrigeration machine. In most cases false load will be required to achieve the specified capacity.

7.3.6.1 If false load is applied to the building equipment, heating media should be added gradually and in incremental manner so that no overloading of air handling equipment and test refrigeration machine occurs. Considerable amount of time may be needed to have the entire system stabilized at the desired temperatures. The Team should evaluate the natural building load (internal load and weather) at the time of test to fully utilize these loads so that the amount of false load may be kept to a minimum.

7.3.6.2 If false load is applied to the temporary heating equipment and/or crossover piping between the condenser and evaporator, heat should be added gradually and cross over valves manipulated to give the specified temperature differentials of both condenser and chilled water. The water flow rates of the condenser and evaporator should be checked constantly to maintain the specified rates.

7.3.7 While load is being increased, monitor the compressor current draw. The maximum current shall not exceed the specified demand limit.

7.3.8 Adjust chilled water leaving temperature setting slightly down to initiate opening of compressor prerotation vanes and observe the operation of vane actuator. The operation of vane actuator shall not "hunt".

7.3.9 Condenser water temperature control and/or cooling tower control may need to be adjusted to obtain the specified condenser water conditions at full load. If during the time of test the outside air wet bulb temperature is higher than that of the specified for the cooling tower and the specified condenser water temperature is not attainable (chances of this is rare), the test must be postponed until the outside air wet bulb temperature drops below the specified value of the cooling tower.

7.3.10 After water flow rates and temperature of both condenser and evaporator have achieved the specified values, the refrigeration machine shall run for a minimum of one (1) hour. Data shall be recorded at 10 minute intervals. Minor adjustment of water flow rates and temperature may be needed during this period. The test setup is considered stabilized and test data for full load performance may be taken, if 3 sets of data (30 minutes total time), after any adjustment, are within the tolerances as listed below:

7.3.10.1 Water flow rate +/- 5% of specified values;

7.3.10.2 Water temperature +/- 0.6 °C (1 °F) of specified values.

7.3.11 Data shall be taken at 10 minute intervals. A minimum of three sets of data shall be averaged for capacity and energy calculations.

7.3.12 Data to be recorded:

7.3.12.1 Chilled water leaving temperature.

7.3.12.2 Chilled water differential temperature.

7.3.12.3 Condenser water entering temperature.

7.3.12.4 Condenser water differential temperature.

7.3.12.5 Chilled water entering and leaving pressure.

7.3.12.6 Condenser water entering and leaving pressure.

7.3.12.7 Chilled water flow primary element differential pressure or other flow instrument output.

7.3.12.8 Condenser water flow primary element differential pressure or other flow instrument output.

7.3.12.9 Wattmeter output.

7.4 Part load tests. Part load tests should follow immediately after the full load test. Unless the part load conditions are specified in the project specification (in cooling capacity or percentage of full load), part load tests shall be performed at 75%, 50%, and 25% of the full load cooling capacity. The chilled water leaving, condenser water leaving and condenser water entering temperature shall be the same as for full load test, except for 25% capacity test where the entering condenser water temperature shall be 19.1 °C (66.3 °F). The chilled water temperature differentials shall be as calculated from equation expressed in Section 8.2 for part load cooling output.

7.4.1 Reduce machine load by the combination of the following ways: reducing the building load; reducing the false load; manipulating the crossover valves; and manipulating the plant chilled water mixing control valve on the chilled water return pipe. The new load shall be stabilized at the largest part load under the full load.

7.4.2 Adjust condenser water temperature control to the specified value of the part load.

7.4.3 Follow the same procedures as outlined previously for full load test (steps 7.3.9 through 7.3.12), except that pressure measurements at entering and leaving points of evaporator and condenser need not be performed.

7.4.4 Repeat the same procedures for all other part load tests. If unstable conditions of compressor occur (surge), abort the test. Follow manufacturer's recommended procedures to stop the compressor operation. See capacity control test later for detecting compressor surge.

7.4.5 Cut off all false load and restore all valves to their normal operation modes.

7.4.6 When the compressor is coasting down, observe and record the oil pressure gage. The oil pressure shall not be lower than the recommended pressure as long as the compressor shaft is turning.

7.5 Capacity control test. This test is performed concurrently with the full load and part load tests. The purpose of this test is to verify the correct sequencing of the operation when the load changes.

7.5.1 After the full load test, set the chilled water leaving thermostat up slowly till the start of compressor coastdown. Then set the thermostat lower to make the circuit again by observing indicating light. A timer prevents rapid cycling of the compressor. Count the time from the start of compressor coastdown to the restart of the compressor. This time must be not less than the manufacturer's recommended time. Observe the prerotation vane's position during the period the compressor is off and restart. The vanes should be fully closed when the compressor is off. They should stay closed before the compressor reaches full speed, then open to their preset fully opened position.

7.5.2 While the building load is reduced for various stages of part load tests, observe the running of the compressor. There shall be no excessive noise and vibration. Special attention should be paid to very low load tests to detect surge. Among other operating parameters, surge depends on the amount of flowing refrigerant, prerotation vane position, and water temperature. Therefore observations should be made for all part load conditions specified, since condenser water temperature specified for part loads may be different. A current meter shall be used to monitor the current draw of the compressor during load changes. Marked fluctuation of current draw indicates compressor surge.

7.6 Cooling plant system tests. These tests are basically for interlocking of cooling plant equipment rather than refrigeration machine itself. Therefore, these tests much depend on the design of the plant. Project drawings and specifications must be thoroughly studied.

7.6.1 Test interlocking of plant components. Compressor shall not start before condenser water and chilled water pumps are started, if they are in automatic mode.

7.6.2 Test lead-lag control. Verify the positions of lead-lag switch with the sequencing of refrigeration machine operations.

7.6.3 Test automatic system start control. If the cooling system is designed for automatic start by sensing outside air temperature or by timer settings, the sensing bulb of the temperature controller shall be placed in temperature bath set at the specified temperature or the timer shall be manipulated to the specified on/off time. The cooling system shall be observed to act in their correct sequence.

## 8. Calculations and rate performance.

8.1 Full load test. The full load refrigerating capacity shall be calculated as follows by using the averaged values of the test data (at least 3):

$$Q_{out} = w\ (c_p)\ (T_e - T_l)$$

$$Q_{in} = W \qquad \text{(For SI)}$$

$$Q_{in} = W \times 3.413 \qquad \text{(For Customary)}$$

where: $Q_{out}$ = cooling capacity, J/s (Btu/h)
$w$ = chilled water mass flow rate, kg/s (lb/h), see SE-37, 39, 41, or 43, EXHIBIT 2-B.
$c_p$ = specific heat of water, J/(kg °C) [Btu/(lb °F)] at mean temperature of $T_e$ and $T_l$
$T_e$ = chilled water supply temperature, °C (°F)
$T_l$ = chilled water return temperature, °C (°F)
$Q_{in}$ = power input of machine, J/s (Btu/h)
$W$ = measured watt meter reading

8.2 Part load test. Use the same equations as for full load test. All sets of specified conditions or percent of part load conditions of 7.4 shall be calculated.

8.3 Rate performance.

8.3.1 The full load capacity of the machine must be not less than the specified full load capacity.

8.3.2 The full load power rate shall not be more than the specified full load power rate.

8.3.3 The part load power rates must not be more than the specified rates.

8.3.4 The pressure drop of chilled water in evaporator shall not be more than 2.5 % of that specified.

8.3.5 The pressure drop of condenser water in condenser shall not be more than 2.5 % of that specified.

## EXHIBIT 3-D RECIPROCATING REFRIGERATION MACHINE TEST PROCEDURE

1. Scope. The test procedures described in this EXHIBIT apply to packaged liquid chilling refrigeration machines using electric driven reciprocating compressors for refrigerant compression to achieve cooling effects. Electric motors may be open or hermetic types. Condensers may be water cooled or air cooled.

2. Purpose.

2.1 To verify full capacity of the installed refrigeration machine for meeting the specified capacity without exceeding the specified power input.

2.2 To verify part load power consumption of the machine not exceeding the specified part load power limits at the specified part loads.

2.3 To verify other limiting conditions set in the project specifications, such as maximum water side frictions of the heat exchangers.

2.4 To verify ability of cooling capacity control of the machine without encountering undesirable effects.

2.5 To verify operations of all components meeting their intended functions.

2.6 To verify safety operation of the machine.

3. Industry standards.

3.1 ARI Standard 590 (Standard for Reciprocating Water-chilling Packages) prescribes requirements for testing of packaged reciprocating water chillers. It specifies the basis for testing, rating, and publishing of capacities and power requirements. These machines are tested and rated at full load under the following conditions:

| | |
|---|---|
| Leaving chilled water temperature | 6.7 °C (44 °F) |
| Entering chilled water temperature | 12.4 °C (54 °F) |
| Fouling factor of water side surfaces | |
| non-ferrous tubes | 0.000088 $m^2$ °C/W (0.0005 °F h $ft^2$/Btu) |
| steel tubes | 0.000176 $m^2$ °C/W (0.0010 °F h $ft^2$/Btu) |
| Water cooled units: | |
| Entering condenser water temperature | 29.4 °C (85 °F) |
| Leaving condenser water temperature | 35 °C (95 °F) |

Air cooled and evaporatively cooled units:
- Entering air dry bulb temperature — 35 °C (95 °F)
- Entering air wet bulb temperature (evap cooled only) — 23.9 °C (75 °F)

Heat reclaim units:
- Entering condenser water temperature (water cooled) — 23.9 °C (75 °F)
- Entering air dry bulb temperature (air cooled) — 4.4 °C (40 °F)
- Heat reclaim condenser entering and leaving temperature:
  - Water cooled -- 40.6 to 48.9 °C (105 to 120 °F) or 35 to 48.9 °C (95 to 105 °F)
  - Air cooled -- 21.1 to 35 °C (70 to 95 °F)

Package with remote condenser:
- Saturated discharge temp (water or evap cooled) — 40.6 °C (105 °F)
- Liquid refrigerant (water or evap cooled) — 35 °C (95 °F)
- Saturated discharge temp (air cooled) — 48.9 °C (120 °F)
- Liquid refrigerant (air cooled) — 43.3 °C (110 °F)

Part load test. A minimum of two part load tests are required. Depending on the unloading steps of the compressor, the part loads and test condition requirements vary (see paragraph 5.2). The conditions of entering condenser water, air, or refrigerant are given as:

Condenser inlet conditions = A x B + C

where A and C are constants as listed in table below
B = % full load compressor displacement

| | A | C |
|---|---|---|
| Condenser entering air dry bulb, °C (°F) (air cooled) | 0.4 | 55 |
| Condenser entering air wet bulb, °C (°F) (evap cooled) | 0.1 | 65 |
| Condenser entering water temperature, °C (°F) (water cooled) | 0.1 | 75 |
| Saturated discharge temp of air cooled with remote condenser, °C (°F) | 0.4 | 80 |
| Saturated discharge temp of water or evap cooled with remote condenser, °C (°F) | 0.1 | 95 |

Water flow rate for water cooled units is the same as full load test (i.e. 0.538 L/s per kW (3 gpm/full load ton)). The liquid refrigerant temperature of remote condensers is 5.6 °C (10 °F) below saturated discharge temperature calculated above.

3.2 Among other requirements, ARI Standard 590 requires the following safety controls:

High refrigerant pressure cutout,
Cooler ambient freeze protection for cooler located outdoors,
Cooler water freeze protection, and
Hermetic compressor motor protection.

3.3 ASHRAE Standard 30 (Methods of Testing Liquid Chilling Packages) describes methods of testing of liquid chilling refrigeration machines for their performance ratings. This standard does not specify the test conditions. Power measurement is for compressor driver and all auxiliaries.

3.4 ASHRAE Standard 15 (Safety Code for Mechanical Refrigeration) covers a much wider range of requirements than the refrigeration machine itself. Its purpose is to assure the safe design, construction, installation, operation, and inspeetion of refrigeration systems.

3.5 ASHARE Standard 90 (Energy Conservation in New Building Design) sets forth the requirements for the design of new buildings, including energy performance of HVAC equipment. The latest edition should be used for minimum performance requirements. The energy input to all auxiliary components of the refrigeration machine is included (consistent to ASHRAE Standard 30 requirements).

## 4. Preparation for test.

4.1 It is assumed that, before the scheduled test, the project contractor or manufacturer's representative has prepared the refrigeration machine in according to the recommendations of the manufacturer for startup and operation and an inspection of the refrigeration system by the Team has taken place (see EXHIBIT 3-A for inspection).

4.2 All measurement and test instruments must be calibrated before testing, unless documents can be shown satisfactorily that the instruments are in calibration (see Chapter 2 for calibration of instruments). Instruments supplied with the machine may be used to take test data, if they are calibrated and the accuracies satisfy the minimum tolerance requirements of tests.

4.3 In most cases a false load is needed for full load performance test. Depending on individual project circumstances, false load may be introduced at the equipment room close to the refrigeration machine to be tested or to the building equipment installed as parts of the building facility (such as air handling systems). The former approach may require temporary equipment to provide heat source, piping from the heat source to the refrigeration machine or cross-over between the condenser and the evaporator (for water cooled condenser units only), and accessories such as shut-off valves and temperature controlling mixing valves. If cross-over of chilled water and condenser water is used, the

Team should review the piping layout to be sure that water entering both evaporator and condenser may be adjusted individually to those of the specified values. The disadvantage of the latter approach is the long lagging time for the temperature at the refrigeration machine to stabilize (from the time to introducing false load at the air handling systems to achieve stable and desired conditions at the test machine). After it is determined the approach to take based on cost comparisons, good coordination between all involved parties is essential.

4.4 The heat exchanger tubes may need to be cleaned to yield the specified fouling factors. Oil film needs to be cleaned when tubes are new. If the refrigeration machine has been running for some time to provide temporary cooling, excessive scale inside the water tubes may have accumulated. This is especially important for condenser tubes, because of the low quality of the condenser water and higher temperature of the tube surface. It is difficult to measure the actual fouling factor or scale thickness in the field. Only actual cleaning will assure the correct performance of the machine. The Team should obtain written statement from the contractor or witness the cleaning operation that the tubes are cleaned according to the manufacturer's recommendations (such as using chemicals). If the machine has been in operation, the contractor or manufacturer's representative must make the decision of cleaning tubes, since chillers with scaled tubes may not pass the power consumption criteria of the contract specification and the commissioning tests.

## 5. Recommended tests.

5.1 Full load test. The refrigeration machine must deliver the specified cooling capacity under the specified conditions. The specified conditions may be different from the basis of the manufacturer's published and selected conditions. Project specification usually specifies the entering and the leaving chilled water temperature, and/or the water flow rates, the maximum water friction of the heat exchanger(s), the operating conditions of the condenser, and the maximum power consumption rate at these specified conditions. The maximum water velocity in the heat exchanger tubes may also be specified. Each of these ratings or limitations must be verified by testing directly or verified by deducing from test data. Since the capacities of air cooled condensers and evaporative condensers depend on the conditions of the ambient air, the full load test may not verify the capacities of the condensers. If the conditions of the ambient air is not as specified during this test, the full capacity test is for the packaged units excluding the condensers. The capacities of these condenses (air cooled or evaporatively cooled) must be tested separately as described in EXHIBIT 3-F, HEAT REJECTION EQUIPMENT TEST PROCEDURES.

5.2 Part load test. Depending on the refrigeration machine's part load performance curve, the energy performance of a machine may vary considerably. In order to have optimum energy performance for the entire cooling season, more than one part load conditions may be specified. The chiller performance at these specified part load shall be tested.

5.3 Capacity control test. With reduced load the machine should respond to reduce its capacity and vice versa. The test should verify the automatic capacity change following load changes without running into unstable conditions for the entire range of capacity from full load to minimum load as specified. Capacity control involves step control of cylinder unloading and/or compressor sequencing.

5.4 Safety control test. To test the refrigeration machine's safety controls so that it will not be damaged during unforeseen events. In additions to the controls required in ARI Standard 590 (see paragraph 3 of this EXHIBIT, Industry standards), other safety features are usually specified, such as refrigerant circuit low pressure cutout, low oil pressure cutout, non-recycling compressor overload safety, etc. All these safety controls, if specified, should also be tested.

5.5 Cooling plant system test. This test involves interlocking of condenser pump, chilled water pump, cooling tower operation, and other cooling plant components, such as sequencing of chillers.

**6. Instrumentation.** The required measurement, minimum accuracies, and measurement precautions are given below:

6.1 Temperature.

6.1.1 Chilled water temperature leaving evaporator. The measurement system error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.2 Direct measurement of temperature differential of the chilled water entering and the leaving evaporator. This measurement is preferred than deducing the difference from separate temperature measurements at the entering and the leaving chilled water, since it minimizes the errors of calibration of two temperature measurements. The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.3 Condenser water temperature entering condenser (water cooled). The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.4 Direct measurement of temperature differential of the condenser water entering and the leaving condenser (water cooled) for the same reason as given for chilled water measurement. Same accuracy requirement as for chilled water, +/- 0.1 °C (0.2 °F).

6.1.5 For air cooled units, measure the dry bulb temperature of air entering condensing coil. The measurement error shall not exceed +/- 0.3 °C (0.5 °F).

6.1.6 For evaporatively cooled units, measure the wet bulb temperature of air entering evaporative cooler. The measurement error shall not exceed +/- 0.5 °C (1 °F).

6.1.7 For units with remote condensing units, measure the saturated discharge temperature of the refrigerant at the refrigeration machine (not at the condenser end). The measurement error shall not exceed +/- 0.3 °C (0.5 °F).

6.1.8 For units with remote condensing units, measure the liquid refrigerant temperature of the refrigerant at the refrigeration machine (not at the condenser end). The measurement error shall not exceed +/- 0.3 °C (0.5 °F).

6.1.9 The temperature sensor locations for temperature measurements are important. For water measurement, they should be located to sense well mixed bulk water temperature. If chilled water or condenser water is used to cool any component of the refrigeration machine, the temperature sensors must be located to include the effects of this cooling. For air measurement (dry and wet bulb), pay attention that the air at the point of measurement is the same that enters the heat exchangers.

6.1.10 The thermometers or temperature gages, supplied as integral parts of the refrigeration machine for maintenance purposes, such as for bearing, oil, refrigerant, etc., shall be calibrated to have errors less than +/-0.6 °C (1 °F). They shall not be used for commissioning tests unless they are verified to meet the minimum accuracy requirements as stated previously.

6.1.11 Temperature sensors and thermometers for water and refrigerant measurement are usually installed in wells. They may be removed from equipment and calibrated either in laboratory or in field. Wells should be refilled with thermal conducting compound when replacing sensors.

6.2 Water flow rate.

6.2.1 Chilled water pipe. The total error of combined sensing and readout devices shall not exceed +/- 3% of measured quantity.

6.2.2 Condenser water pipe. The total error of combined sensing and readout devices shall not exceed +/- 3% of measured quantity.

6.2.3 It is very important to check if the primary element location of the flow meters are appropriate. The minimum pipe lengths upstream and downstream of the primary element must be not less than those given in Chapter 2. Avoid areas where water flow may be swirl (e.g. after consecutive elbows). If space is tight, using of flow straighteners is very helpful.

6.2.4 If chilled water or condenser water is used to cool any component of the refrigeration machine, the primary element of the flow meter must be located to include the effects of this flow.

6.2.5 In majority of installations the water flow rates of reciprocating refrigeration machines are of fixed values. Without having to consider flow ranges, the type of flow meters to be used for permanent installation or just for functional performance tests can be easily selected. If differential pressure type (orifice plate or venturi, etc.) is used, the primary element with the largest throat diameter satisfying the required accuracy should be selected.

6.3 Pressure instrument.

6.3.1 For differential pressure type primary element - water or mercury manometer, or electronic pressure readout unit. Manometers should read accurately to +/- 24.9 Pa (0.1 in. of water). Total error of primary element and readout unit shall not exceed +/- 3% of flow.

6.3.2 The pressure instruments supplied with the machine for operation and maintenance purposes, such as pressure gages for oil pressure and refrigerant pressure shall be calibrated in laboratory or in field. When these instruments are taken off the machine, exercise caution so that the media to be sensed shall not be in contact with the atmosphere.

6.3.3 For large chillers where maximum pressure drops of water heat exchangers are specified, pressure gages are usually required and installed at inlet and outlet of evaporators and condensers. These instruments may be used to verify the heat exchanger water pressure drops.

6.4 Energy measurement.

6.4.1 Polyphase watt meter or watthour meter. Error shall not exceed +/- 0.5% of reading.

6.4.2 Measurement of energy shall include that consumed by compressor and auxiliaries.

6.4.3 Check and record electric voltage between feeders and the frequency at the power supply.

**7. Test procedures.** Refrigeration machine manufacturers usually have detailed check out procedures after field installation for their particular models. The following test procedures are designed to be generic and should be used as guidelines only. Since the testing agent is responsible for performing tests and for demonstrating meeting construction documents, the Team must examine all details of installation and operation manuals provided by the manufacturer and coordinate with the testing agent to modify the test procedures given in this guide. However, the intended purposes of these tests must be carried out and their acceptance criteria must be satisfied.

7.1 Safety control and general operational test. This test should be performed before full and part load tests. Certain simulated inputs may be needed to trigger control actions. Therefore some tests are limited to checking safety control circuits instead of creating true cutout situations. Indicating lights and responses of relays, actuators, and compressors are used to confirm the control action. Details of control sequence may differ somewhat between manufacturers and design setup, the Team should be familiar with the wiring diagrams and manufacturer's instructions. The following tests are general procedures for confirming control sequencing function.

7.1.1 Make sure area is clear of personnel. - IMPORTANT!

7.1.2 Check voltage balance of electric power service. The maximum voltage deviation from average of three voltage measurements should not be greater than +/- 1% of the average. In equation form, it is:

$$\%\ \text{voltage imbalance} = \frac{(A,\ B,\ \text{or}\ C) - (A + B + C)\ /\ 3}{(A + B + C)\ /\ 3}$$

where A, B, and C are voltage measurements between phases.

7.1.3 Make sure the crankcase heater has been on and is working by feeling the warmth of the compressor. The heater should be on for at least 24 hours with all valves in the refrigerant lines in open positions.

7.1.4 Check compressor oil level.

7.1.5 With control circuit power connected, test all pilot lights and alarms by pressing the appropriate buttons (if provided).

7.1.6 (For machines with water cooled condensers) Start condenser water pump.

7.1.7 (For machines with water cooled condensers) Check condenser water flow rate. This should be done after cooling tower is readied for operation. If the flow rate differs substantially from that of the specified rate, adjust flow balancing device on condenser water line to approximately the required rate.

7.1.8 (For machines with water cooled condensers) Check temperature of entering condenser water. The cooling tower temperature control should be adjusted to provide the specified condenser water temperature.

7.1.9 (For evaporatively cooled machines with remotely evaporative cooler) Turn on evaporative cooler unless refrigeration machine is interlocked to start the evaporative cooler automatically.

7.1.10 Start chilled water pump.

7.1.11 Check and adjust chilled water flow rate to approximately specified rate.

7.1.12 Check and set chilled water temperature thermostat to supply the specified chilled water. Machine manufacturer's instruction may be needed for determining set point (depending on controller throttling range, compressor configuration, and allowed water temperature rise).

7.1.13 Start machine operation by pushing "on" button.

7.1.14 Confirm compressor starting and energizing of liquid line solenoid valve after a preset time delay. Compressor should start with only first step of cylinder loaded.

7.1.15 (For air cooled and evaporately cooled machines) Make sure rotation direction of fan is correct.

7.1.16 Test temperature actuated safety controls. Set temperature bath to the trip temperature of the control as recommended by the machine manufacturer. Remove temperature sensor from well and place in temperature bath. Vary the bath temperature +/- 1.1 °C (2 °F) slowly. By observing pilot light, measuring electric potential at appropriate wiring junction, or observing other responses of the machine, the make and break point of the chiller circuits shall be recorded. Also record the set point of the temperature switch. The tolerance of the set point and the actual break point shall not exceed 0.6 °C (1 °F). The temperature switches to be tested shall include chilled water low temperature cutout and any other temperature sensing safety devices. For air cooled units located outdoors, heating cables equipped with thermostats are usually specified for evaporators in cold climatic regions. It is not practical to expose and test this heating system due to the thermal insulation covering, unless its functioning is obviously questionable.

7.1.17 Test flow actuated safety controls. When flow switches in the chilled and the condenser water lines are specified to stop the compressor when low or no flow conditions exist, test these switches by disengaging interlocking between pump starters and compressor starter and switching off the respective water pumps or by turning off valves in the chilled and the condenser water pipes (providing the pipe arrangement permit turning valves off) to the machine. The compressor should stop to verify the functioning of this safety control.

7.1.18 Test pressure actuated safety controls. Check to be sure that the refrigerant line to high pressure safety switch and the high pressure gauge are located on compressor side of discharge service valve. Slowly close compressor discharge service valve until compressor power is cut. This is the high pressure cutout and its pressure should be recorded. To restart the compressor, restore the start circuit (see manufacturer's operation manual) and reopen the discharge service valve. For compressors equipped with time delay, the time elapsed between compressor cutout and cutin should be recorded and compared with manufacturer's specifications. The low pressure safety switch is tested by slowly closing the suction service valve until the compressor is cut out. Reopening the suction valve should restart the compressor. The cutin and cutout pressures of the test results shall be compared with the manufacturer's recommended pressure as listed in the machine manual. The differences of the actual recorded pressure and recommended pressure shall not exceed the tolerances given by the machine manufacturer. For multi-compressor machines there may be more than one high and low pressure switches. Each switch shall be tested.

7.1.19 Check oil level again after machine has been running for at least 1/2 hour. Oil should have no foam and at correct level. If oil pressure gage is specified or installed, record pressure.

7.1.20 Check refrigeration level through sight glass for refrigerant undercharge. There should be no bubbles. Measure and record liquid line pressure and temperature. Calculate subcooling to verify refrigerant charge.

7.1.21 Load the machine gradually. With constant water flow rate through the evaporator, the temperature differential of the chilled water entering and leaving the evaporator and the numbers of active cylinders and compressors indicates the loading condition of the machine. In most cases false load will be required.

7.1.21.1 If false load is applied to the building equipment, heating media should be added gradually and in incremental manner so that no overloading of air handling equipment and test refrigeration machine occurs. The Team should evaluate the natural building load (internal load and weather) at the time of test to fully utilize these loads so that the amount of false load may be kept to a minimum.

7.1.21.2 If false load is applied to the temporary heating equipment and/or crossover piping between the condenser and evaporator (water cooled machines), heat should be added gradually and cross over valves manipulated to give the specified temperature differentials of both condenser and chilled water. The water flow rates of the condenser and evaporator should be checked frequently to maintain the specified rates.

7.1.22 While load is being increased, observe and record the return chilled water temperature when the loading of cylinders and compressors occur. The temperature should agree with the control step settings. Also monitor the compressor current draw. The maximum current shall not exceed the specified demand limit.

7.1.23 Check compressor discharge pressure for refrigerant overcharge. The discharge pressure and the condensing media temperature relationship should be obtained from the machine manufacturer. However, non-condensibles, poor heat transfer, improperly adjusted backpressure valve, etc. may also cause high discharge pressure. Refrigeration overcharge may also determined by measuring liquid subcooling.

7.1.24 (For air cooled and condenserless machines) Test head pressure control. Head pressure control must maintain minimum head pressure during low ambient operation. When machine unloads, head pressure tends to drop presenting opportunity to observe head pressure control. Depending on manufacturer's preference (air cooled type) and system design (condenserless type), there are various ways to control head pressure during low ambient applications. The Team should be familiar with the submittals for the chiller installed. The following examples are for machines with simple ambient temperature and head pressure controls.

7.1.24.1 For ambient temperature control. Place temperature sensor in liquid temperature bath. Adjust bath temperature to the project specified or manufacturer's recommended temperature. Observe and confirm condenser control actions (fan, damper or other action as specified).

7.1.24.2 For head pressure control. By manually blocking condenser air flow or fan operation, observe and confirm head pressure controller signals.

7.1.25 Test lead-lag compressor control arrangement by manipulating lead-lag switches. Confirm sequencing by observing compressor actions.

7.1.26 Test automatic system start control. If the cooling system is designed for automatic start by sensing outside air temperature or by timer settings, the sensing bulb of the temperature controller shall be placed in temperature bath set at the specified temperature or the timer shall be manipulated to the specified on/off time. The cooling system shall be observed to act in their correct sequence. Automatic start/stop controls should not bypass automatic pumpdown control circuit.

7.2 Full load test. This test shall be performed immediately after safety control and general operational control tests. Test procedures depend on condenser arrangement. Note that before recording full load data, verify that hot gas by-pass is off. The manual valve on the hot gas bypass may be turned off during full load test.

7.2.1 Chiller with water cooled condenser.

7.2.1.1 Add false load until the chiller is fully loaded (all steps of all compressors are loaded).

7.2.1.2 Check flow rate of chilled water to specified value. Adjust balancing device if necessary.

7.2.1.3 Adjust chilled water supply and chilled water return temperature to those of the specified by adjusting chilled water temperature controller and the amount of false load.

7.2.1.4 Check flow rate of condenser water to specified value. Adjust balancing device if necessary. If temporary crossover between chilled and condenser water pipes are contemplated for adding false load, careful adjustment of valves may be necessary to obtain the specified flow rates and temperatures of the chilled and condenser water. If during the time of test the outside air wet bulb temperature is higher than that of the specified for the cooling tower and the specified condenser water temperature is not attainable (chances of this is rare), the test must be postponed until the outside air wet bulb temperature drops below the specified value of the cooling tower.

7.2.1.5 After water flow rates and temperature of both condenser and evaporator have achieved the specified values, the refrigeration machine shall run for a minimum of one hours. Data shall be recorded at 10 minute intervals. Minor adjustment of water flow rates and temperature may be needed during this period. The test setup is considered stabilized and test data for full load performance may be taken, if 3 sets of data (30 minutes total time), after any adjustment, are within the tolerances as listed below:

* Water flow rate +/- 5% of specified values;

* Water temperature +/- 0.6 °C (1 °F) of specified values.

7.2.1.6 Data shall be taken at 10 minute intervals. A minimum of three sets of data shall be averaged for capacity and energy calculations.

7.2.1.7 Data to be recorded:

* Chilled water leaving temperature.

* Chilled water differential temperature (or chilled water entering temperature).

* Condenser water entering temperature.

* Condenser water differential temperature (or condenser water leaving temperature).

* Chilled water flow primary element differential pressure or other flow instrument output.

* Chilled water entering and leaving pressure (Required only for large chillers where specifications limit maximum water pressure drops).

* Condenser water flow primary element differential pressure or other flow instrument output.

* Condenser water entering and leaving pressure (Required only for large chillers where specifications limit maximum water pressure drops).

* Total Wattmeter output (For compressor and auxiliaries, but does not include chilled and condenser water pumps, see paragraph 6.4).

7.2.2 Chiller with packaged air cooled condenser and remote air cooled condenser.

7.2.2.1 Add false load until the chiller is fully loaded (all steps of all compressors are loaded).

7.2.2.2 Check flow rate of chilled water to specified value. Adjust balancing device if necessary.

7.2.2.3 Adjust chilled water supply and chilled water return temperature to those of the specified by adjusting chilled water temperature controller and the amount of false load.

7.2.2.4 Measure condenser entering air temperature. In most cases it is lower than the project specified air temperature. In order to simulate an operation condition similar to that of the specified, it is necessary to reduce the condenser air flow rate to increase the saturated discharge temperature of the refrigerant so that the actual saturated discharge temperature equals the specified value. Since chillers are always equipped with a pressure gage or other pressure measurement device at the compressor discharge piping, this pressure reading may be converted to indicate the saturated discharge temperature. Depending on the physical arrangement of the condenser coils and the setup of automatic head pressure controls, various ways may be used to reduce the condenser air flow rate, thus raise the compressor discharge pressure and temperature: manually blocking air passage to the condensers, manipulating air dampers or fan controls.

7.2.2.5 After the chilled water flow rate, the temperature of the chilled water, and the compressor discharge pressure/temperature have achieved the specified values, the refrigeration machine shall run for a minimum of one hours. Data shall be recorded at 10 minute intervals. Minor adjustments may be needed during this period. The test setup is considered stabilized and test data for full load performance may be taken, if three sets of data (30 minutes total time), after any adjustment, are within the tolerances as listed below:

* Water flow rate +/- 5% of specified value;

* Water temperature +/- 0.6 °C (1 °F) of specified values.

* Saturated compressor discharge pressure +/- 20.7 kPa (3 psig).

7.2.2.6 Data shall be taken at 10 minute intervals. A minimum of three sets of data shall be averaged for capacity and energy calculations.

7.2.2.7 Data to be recorded:

* Chilled water leaving temperature.

* Chilled water differential temperature (or chilled water entering temperature).

* Chilled water flow primary element differential pressure or other flow instrument output.

* Water pressure at inlet and outlet of evaporator (Required only for large chillers where specifications limit maximum water pressure drops).

* Condenser air entering temperature.

* Saturated compressor discharge pressure.

* Total Wattmeter output (For compressor and auxiliaries, including condenser fan motor).

7.2.3 Chiller with evaporative condenser.

7.2.3.1 Add false load until the chiller is fully loaded (all steps of all compressors are loaded).

7.2.3.2 Check flow rate of chilled water to specified value. Adjust balancing device if necessary.

7.2.3.3 Adjust chilled water supply and chilled water return temperature to those of the specified by adjusting chilled water temperature controller and the amount of false load.

7.2.3.4 Measure dry bulb and wet bulb temperature of air entering evaporative condenser. In most cases it is lower than the project specified air temperature. In order to simulate an operation condition similar to that of the specified, it is necessary to reduce the condenser air flow rate and/or the amount of spraying water to increase the saturated discharge temperature of the refrigerant so that the actual saturated discharge temperature equals the specified value. Since chillers are always equipped with a pressure gage or other pressure measurement device at the compressor discharge piping, this pressure reading may be converted to indicate the saturated discharge temperature. Depending on the physical arrangement of the evaporative condenser and the setup of automatic head pressure controls, various ways may be used to raise the compressor discharge pressure and temperature: manually blocking air passage to the condensers, manipulating air dampers or fan controls to reduce condenser air flow, or manipulate valves on the spray piping to reduce the amount of spray water.

7.2.3.5 After the chilled water flow rate, the temperature of the chilled water, and the compressor discharge pressure/temperature have achieved the specified values, the refrigeration machine shall run for a minimum of one hours. Data shall be recorded at 10 minute intervals. Minor adjustments may be needed during this period. The test setup is considered stabilized and test data for full load performance may be taken, if three sets of data (30 minutes total time), after any adjustment, are within the tolerances as listed below:

* Water flow rate +/- 5% of specified value;

* Water temperature +/- 0.6 °C (1 °F) of specified values.

* Saturated compressor discharge pressure +/- 20.7 kPa (3 psig).

7.2.3.6 Data shall be taken at 10 minute intervals. A minimum of three sets of data shall be averaged for capacity and energy calculations.

7.2.3.7 Data to be recorded:

* Chilled water leaving temperature.

* Chilled water differential temperature (or chilled water entering temperature).

* Chilled water flow primary element differential pressure or other flow instrument output.

* Water pressure at inlet and outlet of evaporator (Required only for large chillers where specifications limit maximum water pressure drops).

* Dry and wet bulb temperatures of air entering evaporative condenser.

* Saturated compressor discharge pressure.

* Total Wattmeter output (For compressor and auxiliaries, including fan and pump motor of evaporative condenser).

7.3 Part load tests. Part load tests shall be performed immediately after the full load test. Unless the part load conditions are specified in the project specification (in cooling tonnage or percentage of full load), part load tests shall be performed at two load steps - a step closest to 60% of full load and the lowest step. If the chiller has only one step of unloading or no capability of unloading, it shall be tested at 60% and 40% of full capacity. The chilled water leaving temperature shall be as for full load. The condenser entering conditions are the same as those of ARI Standard 590 (see paragraph 3.1). They are listed below for 60%, 50%, and 40% of full load.

| | Part load 60% | Part load 50% | Part load 40% |
|---|---|---|---|
| Entering cond. w. temp. °C (°F) (water cooled) | 81 | 80 | 79 |
| Saturated disch. temp. °C (°F) (air cooled, evap.cooled) | 104 | 100 | 96 |

7.3.1 Reduce machine load by the combination of the following ways: reducing the building load; reducing the false load; manipulating the crossover valves; and manipulating the plant chilled water mixing control valve on the chilled water return pipe. The new load shall be stabilized at the larger part load of the two part load described in paragraph 7.3 above.

7.3.2 Follow the same procedures as outlined previously for full load tests (paragraphs 7.2.1 for units with water cooled condensers, paragraph 7.2.2 for units with air cooled condensers, and paragraphs 7.2.3 for units with evaporative condensers), except that water pressure measurements at inlet and outlet of heat exchangers need not be performed.

7.3.3 Repeat the same procedures for the lower part load tests.

7.3.4 After tests, cut off all false load and restore all valves to their normal operation modes.

## 8. Calculations and rate performance.

### 8.1 Full load test.

8.1.1 Full load capacity. The full load refrigerating capacity shall be calculated as follows by using the averaged values of the test data (at least 3):

$$Q_{out} = w\ (c_p)\ (T_e - T_1)$$

$$Q_{in} = W \qquad \text{(For SI)}$$

$$Q_{in} = W \times 3.413 \qquad \text{(For Customary)}$$

where: $Q_{out}$ = cooling capacity, J/s (Btu/h)
$w$ = chilled water mass flow rate, kg/s (lb/h), see SE-37, 39, 41, or 43, EXHIBIT 2-B.
$c_p$ = specific heat of water, J/(kg °C) [Btu/(lb °F)] at mean temperature of Te and Tl
$T_e$ = chilled water supply temperature, °C (°F)
$T_1$ = chilled water return temperature, °C (°F)
$Q_{in}$ = power input of machine, J/s (Btu/h)
$W$ = measured watt meter reading

8.2 Part load test. Use the same equations as for full load test. Both part load conditions of paragraph 7.3 shall be calculated.

8.3 Rate performance.

8.3.1 The full load capacity of the machine must be not less than the specified full load capacity.

8.3.2 The full load power rate shall not be more than the specified full load power rate.

8.3.3 The pressure drops of chilled and condenser water in evaporator and water cooled condenser shall not be higher than those specified. This requirement applies only to large chillers where maximum water pressure drops are given in the project specifications.

8.3.4 The part load power rate must not be more than the specified rates.

## EXHIBIT 3-E ABSORPTION REFRIGERATION MACHINE TEST PROCEDURE

1. **Scope.** The test procedures described in this EXHIBIT apply to absorption refrigeration machines using steam or hot water as energy source.

2. **Purpose.**

2.1 To verify full capacity of the machine for meeting the project specified capacity without exceeding the specified energy input.

2.2 To verify part load energy input of the machine not exceeding the specified part load energy limits at the specified part loads.

2.3 To verify other limiting conditions set in the project specifications, such as maximum water side frictions of the heat exchangers.

2.4 To verify ability of cooling capacity control of the machine without encountering undesirable effects.

2.5 To verify operations of all components meeting their intended functions.

2.6 To verify safety operation of the machine.

3. **Industry standards.**

3.1 ARI Standard 560 (Standard for Absorption Water-chilling Packages) prescribes requirements for testing of absorption water chillers. It specifies the basis for testing, rating, and publishing of capacities and energy requirements. These machines are tested and rated at full load under the following conditions:

| | |
|---|---|
| Leaving chilled water temperature | 6.7 °C (44 °F) |
| Entering chilled water temperature | 12.2 °C (54 °F) |
| Fouling factor of water side surfaces | 0.000088 $m^2$ °C/W<br>(0.0005 hr $ft^2$ °F/Btu) |
| Entering condenser water temperature | 29.4 °C (85 °F) |

For part load performance, the chilled water temperature, chilled water flow rate, and condenser water flow rate remain the same as for full load. The entering condenser water temperature varies linearly with load, decreasing from 29.4 °C (85 °F) for full load to 15.6 °C (60 °F) for no load.

The standard requires that the published capacity be not less than 95% of test capacity and that the published energy consumption rate and condenser water flow rate be not more than 105% of their corresponding test rates.

The required safety controls include low temperature cutout and provisions for interlocking to stop operation of the chiller if chilled water flow fails.

3.2 ASHARE Standard 90 (Energy Conservation in New Building Design) sets forth the requirements for the design of new buildings, including energy performance of HVAC equipment. The latest edition should be used for the mimimum performance requirements.

## 4. Preparation for test.

4.1 It is assumed that, before the scheduled test, the project contractor or manufacturer's representative has prepared the refrigeration machine in according to the recommendations of the manufacturer for startup and operation and an inspection of the refrigeration system by the Team has taken place (see EXHIBIT 3-A for inspection).

4.2 All measurement and test instruments must be calibrated before testing, unless documents can be shown satisfactorily that the instruments are in calibration (see Chapter 2 for calibration of instruments). Instruments supplied with the machine may be used to take test data, if they are calibrated and the accuracies satisfy the minimum tolerance requirements of tests.

4.3 In most cases a false load is needed for full load performance test. Depending on individual project circumstances, false load may be introduced at the equipment room close to the refrigeration machine to be tested or to the building equipment installed as parts of the building facility (such as air handling systems). The former approach may require temporary equipment to provide heat source, piping from the heat source to the refrigeration machine or cross-over between the condenser and the evaporator, and accessories such as shut-off valves and temperature controlling mixing valves. If cross-over of chilled water and condenser water is used, the Team should review the piping layout to be sure that water entering both evaporator and condenser may be adjusted individually to those of the specified values. The disadvantage of the latter approach is the long lagging time for the temperature at the refrigeration machine to stabilize (from the time to introducing false load at the air handling systems to achieve stable and desired conditions at the test machine). After it is determined the approach to take based on cost comparisons, good coordination between all involved parties is essential.

4.4 The heat exchanger tubes may need to be cleaned to yield the specified fouling factors. Oil film needs to be cleaned when tubes are new. If the refrigeration machine has been running for some time to provide temporary cooling, excessive scale inside the water tubes may have accumulated. This is especially important for condenser and absorber tubes, because of the low quality of the condenser water and high temperature of the tube surface. It is difficult to measure the actual fouling factor or scale thickness in the field. Only actual cleaning will assure the correct performance of the machine. The Team should obtain written statement from the contractor or witness the cleaning operation that the tubes are cleaned according to the manufacturer's recommendations (such as using chemicals). If the machine has been in operation, the contractor or manufacturer's representative must make the decision of cleaning tubes, since chillers with scaled tubes may not pass the thermal performance criteria of the contract specification and the commissioning tests.

## 5. Recommended tests.

5.1 Full load test. The refrigeration machine must deliver the specified cooling capacity under the specified conditions. The specified conditions may be different from the basis of the manufacturer's published and selected conditions. Project specification usually specifies the entering and the leaving chilled water and condenser temperatures, and/or the water flow rates, the maximum water friction of the heat exchanger(s), and the maximum energy consumption rate at these specified conditions. The maximum water velocity in the heat exchanger tubes may also be specified. Each of these ratings or limitations must be proven by testing directly or proven by deducing from test data.

5.2 Part load test. Some project specifications may also specify part load performance (capacities vs. energy consumption rates) for optimum energy performance. The operating conditions of the condenser water temperature are usually different from that of the full load. The chiller performance at part load shall be tested at the specified part load conditions.

5.3 Capacity control test. With reduced load the machine should respond by reducing its capacity and vice versa. The test should verify the automatic capacity change following load changes without running into undesirable conditions for the entire range of capacity from full load to minimum load as specified.

5.4 Safety control test. To test the refrigeration machine's safety controls so that it will not be damaged during unforeseen events. In additions to the controls required in ARI Standard 560 (see paragraph 3 of this EXHIBIT, Industry standards), other safety and operation features provided by the chiller manufacturer (such as non-condensable purging equipment) should be tested.

5.5 Cooling plant system test. This test involves interlocking of condenser pump, chilled water pump, cooling tower operation, and other cooling plant components, such as sequencing of chillers.

**6. Instrumentation.** The required measurement, minimum accuracies, and measurement precautions are given below:

6.1 Temperature.

6.1.1 Chilled water temperature leaving evaporator. The measurement system error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.2 Direct measurement of temperature differential of the chilled water entering and the leaving evaporator. This measurement is preferred than deducing the difference from separate temperature measurements at the entering and the leaving chilled water, since it minimizes the errors of calibration of two temperature measurements. The measurement error shall not exceed +/- 0.1 °C (0.2 °F). If separate measurement of entering evaporator is desired, total measurement error for chilled water entering evaporator shall not exceed 0.1 °C (0.2 °F).

6.1.3 Condenser water temperature entering absorber. The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.4 Direct measurement of temperature differential of the condenser water entering absorber and leaving condenser. Similar to chilled water temperature measurement, the accuracy shall be +/- 0.1 °C (0.2 °F). If condenser water leaving condenser is measured, the measurement error shall not exceed +/- 0.1 °C (0.2 °F).

6.1.5 Hot water measurement (for hot water operated chiller). Same as for chilled water measurement.

6.1.6 Steam and condensate measurement (for steam operated chiller). The measurement error shall not exceed +/- 0.6 °C (1 °F). The steam temperature measurement is for checking the state of steam. The temperature sensing location should be close to the steam control valves. The condensate temperature sensing location should be in the condensate drop leg before steam traps.

6.1.7 The temperature sensor locations for temperature measurements are important. They should be located to sense well mixed bulk water temperature. If chilled water or condenser water is used to cool any component of the refrigeration machine, the temperature sensors must be located to include the effects of this cooling.

6.1.8 The thermometers or temperature gages, supplied as integral parts of the refrigeration machine for maintenance purposes, shall be calibrated to have errors less than +/- 0.6 °C (1 °F). They shall not be used for full and part load tests unless they are verified to meet the minimum accuracy requirements as stated previously.

6.1.9 Temperature sensors and thermometers for water measurement are usually installed in wells. They may be removed from equipment and calibrated either in laboratory or in field. If the sensing elements are removed, wells must be refilled with thermal conducting compound when replacing the elements.

6.2 Water and steam flow rates.

6.2.1 The flow rates of chilled water, condenser water, hot water and steam shall all be measured. The total error of combined sensing and readout devices shall not exceed +/- 3% of measured quantity.

6.2.2 It is very important to check if the primary element location of the flow meters are appropriate. The minimum pipe lengths upstream and downstream of the primary element must be not less than those given in Chapter 2. Avoid areas where fluid flow may be swirl (e.g. after consecutive elbows). If space is tight, using of flow straighteners is very helpful.

6.2.3 If chilled water or condenser water is used to cool any component of the refrigeration machine, the primary element of the flow meter must be located to include the effects of this flow.

6.2.4 In majority of installations the flow rates of chilled and condenser water are of fixed values. Without having to consider flow ranges, the type of flow meters to be used for permanent installation or just for commissioning tests can be easily selected. If differential pressure type (orifice plate or venturi, etc.) is used, the primary element with the largest throat diameter satisfying the required accuracy should be selected.

6.3 Pressure instrument.

6.3.1 For differential pressure type primary element - water or mercury manometer, or electronic pressure readout unit. Manometers should read accurately to +/- 24.9 Pa (0.1 in. of water). Total error of primary element and readout unit shall not exceed +/- 3% of flow.

6.3.2 Steam pressure measurement at chiller inlet. Instrument error shall not exceed 689 Pa (0.1 psig).

6.3.3 Pressure gages are usually specified and installed at inlet and outlet of heat exchangers. These instruments may be used to verify the heat exchanger water pressure drops.

6.3.4 The pressure instruments supplied with the machine or installed by construction contractor for operation and maintenance purposes shall be calibrated in laboratory or in field. When these instruments are taken off the machine, exercise caution so that the media to be sensed shall not be in contact with the atmosphere.

6.4 Energy measurement.

6.4.1 Watt meter or watthour meter shall be used for chiller electrical power measurement. Error shall not exceed +/- 0.5% of reading.

6.4.2 Check and record electric voltage between feeders and the frequency at the power supply.

**7. Test procedures.** Refrigeration machine manufacturers usually have detailed check out procedures after field installation for their particular models. The following test procedures are designed to be generic and should be used as guidelines only. Since the testing agent is responsible for performing tests and for demonstrating meeting construction documents, the Team must examine all details of installation and operation manuals provided by the manufacturer and coordinate with the testing agent to modify the test procedures given in this guide. However, the intended purposes of these tests must be carried out and their acceptance criteria must be satisfied.

7.1 General operational test. This test should be performed before full and part load tests. Certain simulated inputs may be needed to trigger control actions. Therefore some tests are limited to checking safety control circuits instead of creating true cutout situations. Indicating lights and responses of relays, actuators, and other equipment are used to confirm the control action. Details of control sequence may differ between manufacturers and design setup. The Team should be familiar with the wiring diagrams and manufacturer's instructions. The following tests are general procedures for confirming control sequencing function.

7.1.1 <u>Make sure area is clear of personnel</u>. - IMPORTANT!

7.1.2 Make sure all temperature sensors and controllers have been calibrated and functioning properly. These include chilled water supply controller for controlling steam or hot water valves and condenser water temperature controller for cooling tower and/or condenser water by-pass valve. Be sure controllers are set at the project specified temperatures.

7.1.3 Test temperature actuated safety controls. Set temperature bath to the trip temperature of the control as recommended by the machine manufacturer. Remove low temperature cutout sensor from well and place in temperature bath. Vary the bath temperature +/- 1.1 °C (2 °F) slowly. By observing pilot light and measuring electric potential at appropriate wiring junction, the make and break point of the chiller circuits shall be recorded. Also record the set point of the temperature switch. The tolerance of the set point and the actual break point shall not exceed 0.6 °C (1 °F). If the chiller is provided with other safety temperature switches, they shall be tested similarly.

7.1.4 Make sure chilled water pump, condenser water pump, and cooling tower interlocking is functioning properly. Cooling tower should be readied for operation.

7.1.5 Test flow actuated safety controls. When flow switches in the chilled water (required by ARI Standard 560) and the condenser water lines are specified to stop the chiller operation when low or no flow conditions exist, test these switches by disengaging interlocking between water pump starters and switching off the respective water pumps or by turning off valves in the chilled and the condenser water pipes (providing the pipe arrangement permit turning valves off) to the chiller. Their operation may be verified by observing pilot lights, measuring electric potential at appropriate wiring junctions or operation of chiller pumps.

7.1.6 All pilot lights should be checked for proper indication.

7.1.7 Check chilled water and condenser water flow rates. They shall agree with project specified rates. Adjust flow balancing devices if necessary.

7.1.8 Chiller is started in accordance to manufacturer's instructions.

7.1.9 The testing agent (manufacturer's representative or other qualified personnel, see project specifications) shall load the machine gradually until it is fully loaded. With constant water flow rate through the evaporator, the temperature differential of the chilled water entering and leaving the evaporator indicates the loading condition of the machine. In most cases false load will be required.

7.1.9.1 If false load is applied to the building equipment, heating media should be added gradually and in incremental manner so that no overloading of air handling equipment and test refrigeration machine occurs. The Team should evaluate the natural building load (internal load and weather) at the time of test to fully utilize these loads so that the amount of false load may be kept to a minimum.

7.1.9.2 If false load is applied to the temporary heating equipment and/or crossover piping between the condenser water and chilled water, heat should be added gradually and cross over valves manipulated to give the specified temperature differentials of chilled water. The water flow rates of the condenser and evaporator should be checked frequently to maintain the specified rates.

7.1.10 After chiller is fully loaded and operating in stable conditions, withdraw solution samples from generator and absorber with flasks. These samples shall be dried in oven to determine their salt concentration. The concentration shall agree with the manufacturer's recommendations. It is usually the responsibility of the manufacturer's representative to adjust chiller to its most efficient operating conditions.

7.1.11 Operate purge system for at least one hour to remove non-condensables. Take factory recommended procedures to demonstrate that the chiller is free of non-condensables. Also check non-condensables at purge system discharge to be hydrogen free.

7.1.12 Due to the high temperature of the condenser water in the condenser, the condenser tube fouling should be checked. Determine the condensing temperature of the refrigerant by using a refrigerant pressure-temperature chart (also known as lithium bromide equilibrium chart) and by knowing the concentration of solution withdrawn from concentrator and the solution temperature leaving concentrator. The difference between the temperature of concentrated solution leaving concentrator and the vapor condensing temperature at full load shall not exceed the manufacturer's specifications.

7.2 Full load thermal performance test. This test shall be performed immediately after general operational tests.

7.2.1 Check flow rate of chilled water to specified value. Adjust balancing device if necessary.

7.2.2 Adjust chilled water supply and chilled water return temperature to those of the specified by adjusting chilled water temperature controller and the amount of false load.

7.2.3 Check flow rate of condenser water to specified value. Adjust balancing device if necessary.

7.2.4 Adjust condenser water temperature controls and/or cooling tower temperature controls to obtain the specified condenser water temperature (at entering absorber). The purpose of this step is to simulate the effect of design weather. If temporary crossover between chilled and condenser water pipes are used for adding false load, careful adjustment of valves may be necessary to obtain the specified flow rates and temperatures of the chilled water. If during the time of test the outside air wet bulb temperature is higher than that of the specified value for the cooling tower and the specified condenser temperature is not attainable (chances of this is rare), the test must be postponed until the outside air wet bulb temperature drops below the specified value of the cooling tower.

7.2.5 After water flow rates and temperature of both condenser and evaporator have achieved the specified values, the refrigeration machine shall run for a minimum of one hours. Data shall be recorded at 10 minute intervals. Minor adjustment of water flow rates and temperature may be needed during this period. The test setup is considered stabilized and test data for full load performance may be taken, if three sets of data (30 minutes total time), after any adjustment, are within the tolerances as listed below:

7.2.5.1 Water flow rate +/- 5% of specified values;

7.2.5.2 Water temperature +/- 0.6 °C (1 °F) of specified values.

7.2.6 Data shall be taken at 10 minute intervals. A minimum of three sets of data shall be averaged for capacity and energy calculations.

7.2.7 Data to be recorded:

7.2.7.1 Chilled water leaving temperature.

7.2.7.2 Chilled water differential temperature (or chilled water entering temperature).

7.2.7.3 Condenser water entering temperature.

7.2.7.4 Condenser water differential temperature (or condenser water leaving temperature).

7.2.7.5 Chilled water flow primary element differential pressure or other flow instrument output.

7.2.7.6 Chilled water entering pressure.

7.2.7.7 Chilled water leaving pressure.

7.2.7.8 Condenser water flow primary element differential pressure or other flow instrument output.

7.2.7.9 Water pressure of condenser water when entering absorber.

7.2.7.10 Water pressure of condenser water when leaving condenser.

7.2.7.11 Watthour reading for electric consumption.

For hot water operated chiller:

7.2.7.12 Hot water entering temperature.

7.2.7.13 Hot water differential temperature (or hot water entering temperature).

7.2.7.14 Hot water flow primary element differential pressure or other flow instrument output.

7.2.7.15 Hot water entering pressure.

7.2.7.16 Hot water leaving pressure.

For steam operated chiller:

7.2.7.17 Steam temperature before control valve.

7.2.7.18 Steam pressure before control valve. - IMPORTANT.

7.2.7.19 Steam flow primary element differential pressure or other flow instrument output.

7.2.7.20 Condensate temperature.

7.3 Part load tests. If part load thermal performance tests are required in the project specification, part load tests shall be performed immediately after the full load test. The amount of chiller loads, chilled water temperature, and condenser water temperature shall be adjusted in accordance to those specified.

7.3.1 Reduce machine load by the combination of the following ways: reducing the building load; reducing the false load; manipulating the crossover valves; and manipulating the plant chilled water mixing control valve on the chilled water return pipe. The new load shall be stabilized at the largest part load of the part loads specified. The leaving chilled water temperature and the condenser water temperature entering absorber shall be as specified for the part load.

7.3.2 Follow the same procedures as outlined previously for full load tests (paragraphs 7.2), except that the water pressure measurements for chilled, condenser, and hot water need not be performed.

7.3.3 Repeat the same procedures for the next larger part load specified until all specified part loads have been tested.

7.3.4 After tests, remove all false load and restore all valves to their normal operation modes.

## 8. Calculations and rate performance.

### 8.1 Full load test.

8.1.1 Full load capacity. The full load refrigerating capacity shall be calculated as follows by using the averaged values of the test data (at least 3):

$$Q_{out} = w_1 (c_{p1}) (T_{e1} - T_{l1})$$

$$Q_{ine} = W \qquad \text{(For SI)}$$

$$Q_{ine} = W \times 3.413 \qquad \text{(For Customary)}$$

For hot water operated chiller:

$$Q_{inh} = w_2 (c_{p2}) (T_{e2} - T_{l2})$$

For steam operated chiller:

$$Q_{inh} = w_2 (H_2 - c_{p2} \times T_{l2})$$

where:

- $c_{p1}$ = specific heat of chilled water, J/(kg °C) [Btu/(lb °F)] at mean temperature of $T_{e1}$ and $T_{l1}$
- $c_{p2}$ = specific heat of hot water, J/(kg °C) [Btu/(lb °F)] at mean temperature of $T_{e2}$ and $T_{l2}$
- $H$ = enthalpy of steam, J/kg (Btu/lb)
- $Q_{ine}$ = electric energy input to chiller, J/s (Btu/h)
- $Q_{inh}$ = hot water or steam energy input of chiller, J/s (Btu/h)
- $Q_{out}$ = cooling capacity, J/s (Btu/h)
- $T_{e1}$ = chilled water entering temperature, °C (°F)
- $T_{e2}$ = hot water entering temperature, °C (°F)
- $T_{l1}$ = chilled water leaving temperature, °C (°F)
- $T_{l2}$ = hot water leaving temperature, or condensate temperature, °C (°F)
- $W$ = measured watt meter reading.
- $w_1$ = chilled water mass flow rate, kg/s (lb/h), see SE-37, 39, 41, or 43, EXHIBIT 2-B.
- $w_2$ = Hot water mass flow rate, kg/h (lb/h), see SE-37, 39, 41, or 43, EXHIBIT 2-B.

### 8.2 Part load test. Use the same equations as for full load test.

### 8.3 Rate performance.

8.3.1 The full load capacity of the machine must be not less than the specified full load capacity.

8.3.2 The heating energy consumption rate at full and part loads shall not be more than those specified.

8.3.3 The chiller coefficient of performance at full load shall not be less than that specified. The COP is calculated as:

$$COP = \frac{Q_{out}}{Q_{ine} + Q_{inh}}$$

8.3.4 The pressure drop of chilled water in evaporator shall not be more than that specified.

8.3.5 The combined pressure drop of condenser water in absorber and condenser shall not be more than that specified.

8.3.6 The pressure drop of hot water in generator shall not be more than that specified.

## EXHIBIT 3-F HEAT REJECTION EQUIPMENT TEST PROCEDURES

### 1. Scope and general.

1.1 The procedures described in this EXHIBIT apply to testing of heat rejection equipment for refrigeration machines, including factory and field assembled cooling towers, evaporative condensers, and dry coil refrigerant condensers.

1.2 Since the performance of heat rejection equipment depends on the conditions of outside air, it is difficult to test these equipment in the field under exactly the specified conditions. The method of testing of cooling towers and evaporative condensers used in this EXHIBIT is to test these equipment under weather conditions at the time of testing, with certain limitations, and compare test results with the manufacturer supplied test data curves or tables.

1.3 For air cooled condensing coils, the condensing coil capacity is closely proportional to the temperature difference of condensing temperature and air dry bulb temperature. Therefore, the coil capacity tested at a certain outdoor temperature may be converted to design conditions if the condensing temperature and outside air temperature are known. The test procedures in this EXHIBIT is based on this assumption.

1.4 In order to test the performance of air cooled condensers and evaporative condensers accurately, the flow rate of the refrigerant must be measured. However, the installation of additional flanges, valves, flow meters, etc. to facilitate flow rate measurement increases the possibility of refrigerant loss. Therefore, it is a decision of the designers and specifiers whether accurate capacity test is required during the functional tests. The test procedure outlined in this guide assumes that accurate capacity measurements are required.

### 2. Purpose.

2.1 To verify thermal performance of heat rejection without exceeding specified power input.

2.2 To verify operations of all components meeting their intended functions.

2.3 To verify safe operation of the equipment.

# 3. Industry standards.

## 3.1 Cooling tower.

3.1.1 ASME Standard PTC-23 ( Test Code for Atmospheric Water-Cooling Equipment) provides methods and procedures for testing overall performance of atmospheric cooling towers. This code does not set a definite set of test conditions. In stead, it gives limitations of test conditions referencing to tower design conditions. Among these limitations are:

3.1.1.1 Wet-bulb temperature of air not more than 1.7 °C (3 °F) above or 3.9 °C (7 °F) below design wet-bulb temperature. Air temperature may be measured at tower air intake or windward side (relative to tower) of atmospheric air

3.1.1.2 Circulating water flow not more than +/- 10% of design circulating water flow.

3.1.1.3 Range (water in temperature minus water out temperature) not more than +/- 20% of design.

3.1.1.4 Heat load not more than +/- 20% of design.

Manufacturer's performance curves within these limitations are used to compare the test results and tower performance.

3.1.2 CTI Bulletin ATC-105 (Acceptance Test Code for Water Cooling Towers) is very similar to the ASME test code. The major differences are:

3.1.2.1 Wet-bulb temperature of air not more than +/- 5.6 °C (10 °F) of design. Air temperature is measured at tower air intake.

3.1.2.2 As an alternative to using performance curves for comparing test results, this code allows using characteristic curves for estimating thermal performance of the tower at specified conditions.

## 3.2 Air cooled refrigerant condenser.

3.2.1 ARI Standard 460 (Remote Mechanical draft air- Cooled Refrigerant Condensers) prescribes testing and rating requirements for remote air-cooled condensers. The standard rating conditions are, among others:

3.2.1.1 35 °C (95 °F) entering air dry-bulb temperature;

3.2.1.2 51.7 °C (125 °F) refrigerant condensing temperature;

3.2.1.3 87.8 °C (190 °F) entering (condenser) refrigerant vapor temperature.

Degree of refrigerant subcooling is not specified. The condensing coil has no external static pressure ( no external ductwork).

3.2.2 ASHRAE Standard 20 (Methods of Testing for Rating Remote Mechanical-Draft Air-Cooled Refrigerant Condensers) describes test methods and procedures for remote air-cooled condensers. It does not specify test conditions. Methods of measuring refrigerant flow are made by using either calorimeter or orifice plate.

3.3 Evaporative refrigerant condenser.

3.3.1 ASHRAE Standard 64 (Methods of Testing Remote Mechanical-Draft Evaporative Refrigerant Condensers). The testing method is quite similar to that for air cooled condensers. The standard does not specify test conditions, therefore it does not give criteria for comparing with specified thermal performance.

## 4. Preparation for test.

4.1 It is assumed that, before the scheduled test, the construction contractor or manufacturer's representative has prepared the heat rejection equipment in accordance to the recommendations of the manufacturer for startup and operation and an inspection of the equipment and condenser water system, if applicable, has taken place (see EXHIBIT 3-B for inspection).

4.2 All measurement and test instruments must be calibrated before testing, unless documents can be shown satisfactorily that the instruments are in calibration (see Chapter 2 for calibration of instruments). Instruments supplied with the equipment may be used to take test data after they have been calibrated and the accuracies satisfy the minimum tolerance requirements of the tests.

4.3 The heat rejection equipment tests should precede or follow immediately the refrigeration machine tests. Certain measurements and procedures for refrigeration machine may be used or modified for heat rejection equipment test. Examples are condenser water flow rate measurement, application of false load to test equipment, or condenser water temperature measurement in some installations.

4.4 Cooling tower.

4.4.1 Condensing water system must be balanced in accordance to project specifications. If multi-tower are installed, condenser water flow rates to individual towers must be balanced correctly.

4.4.2 Water distribution valves at tower inlet, if installed, must be balanced.

4.4.3 Tower static head (discharge to distribution plate or through nozzles) must be adjusted to specified value.

4.4.4 Water level in the water basin is as recommended by the manufacturer and is stable.

4.4.5 Water is free from debris. Check and clean sump and screen (or strainer) for debris.

4.4.6 Measure wet-bulb temperature at air intake of tower. It must be within +/- 5.6 °C (10 °F) of specified wet-bulb temperature. If wet-bulb temperature of air is beyond these limitations, the test must be postponed until a more appropriate weather.

4.4.7 Check wind velocity where air circulation is not influenced by tower air (or when tower fan is off). The wind velocity shall not be over 268 km/s (10 mph) during the test.

4.4.8 Disable basin temperature control if basin temperature control is specified and provided (i.e. the tower has no automatic temperature control on condenser water temperature).

4.5 Air cooled condenser.

4.5.1 The outdoor temperature during the test must be above 26.7 °C (80 °F).

4.5.2 Disable discharge pressure control during test.

4.5.3 It is assumed that the project specification has specified and the construction contractor has installed pressure gages at coil inlet and outlet, and valved branch pipes with orifice plate at coil inlet (check project specifications for detailed requirements).

4.6 Evaporative condenser.

4.6.1 Make sure spray water is clean and free of debris.

4.6.2 Make sure water level in water basin is as recommended by the equipment manufacturer, the bleed line is balanced, and the makeup valve is working properly.

4.6.3 Measure wet-bulb temperature around air intake. It must be within +/- 5.6 °C (10 °F) of specified wet-bulb temperature. If wet-bulb temperature of air is beyond these limitations, the test must be postponed until a more appropriate weather.

4.6.4 If the condenser is located outdoors, check wind velocity. The wind velocity shall not be over 268 m/s (10 mph) during the test.

## 5. Instrumentation.

### 5.1 Cooling tower.

5.1.1 Condenser water entering temperature (hot water). The measurement system error shall not exceed +/- 0.1 °C (0.2 °F). For multi-tower or multi-cell installation, a preferred measurement location is at the main condenser pipe before any branching. Location of leaving condenser water measurement for chiller test may be used if the distance between the tower and the chiller is less than 15.2 m (50 ft).

5.1.2 Condenser water entering (hot water) and leaving (cold water) temperature differential measurement. Direct measurement of temperature differential is preferred than measuring both entering and leaving temperatures and deducing the difference. The measurement error shall not exceed +/- 0.1 °C (0.2 °F). If differential temperature measurement is difficult to obtain, the leaving condenser water temperature should be measured and the measurement error of this measurement shall not exceed +/- 0.1 °C (0.2 °F). For multi-tower or multi-cell installations, special attention should be given so that the sensor or sensors of the water leaving towers measure the truly mixed water temperature and has minimum influence from pumping and piping heat gains. A good compromise is at the condenser water pump discharge pipe if the pump is within 15.2 m (50 ft) of the tower.

5.1.3 Condenser water flow rate. The measurement system error shall not exceed +/- 3% of measured quantity. Pitot traverse shall be used for determining water velocity. The instruments for condenser flow rate measurement in chiller tests may be used for cooling tower tests.

5.1.4 Wet-bulb temperature of air entering cooling tower. The measurement error shall not exceed +/- 0.6 °C (1 °F). Measurements shall be taken in inlet air stream, at 1.2 m (4 ft) from the tower and 1.5 m (5 ft) above water basin. A minimum of three wet-bulb temperature measurements at different locations (same level) shall be averaged for thermal performance comparisons.

5.1.5 Fan power. Watt meter of watthour meter. Error shall not exceed +/- 0.5% of reading.

### 5.2 Air cooled condenser and evaporative condenser.

5.2.1 Refrigerant temperature at condenser inlet and outlet. The measurement error shall not exceed +/- 0.3 °C (0.5 °F). If no thermometer wells are provided, attach temperature sensors on the outside of refrigerant pipe and cover sensor and pipe with 0.025 m (1 in.) thick mineral wool thermal insulation at least 0.3 m (1 ft) long.

5.2.2 Refrigerant pressure at condenser inlet and outlet. The measurement error shall not exceed +/- 6.89 kPa (1 psig) (see project specification).

5.2.3 Refrigerant flow rate. Measure at condenser outlet with variable area flow meter or turbine flow meter. The measurement error shall not exceed +/- 1% of reading (see project specification).

5.2.4 Fan power rate. Watt meter or watthour meter. Measurement error shall not exceed 0.5% of reading.

5.2.5 Dry bulb temperature of air +/- 0.6 °C (1 °F).

5.2.6 For evaporative condenser only:

5.2.6.1 Wet bulb temperature of air. Measurement error shall not exceed +/- 0.6 °C (1 °F).

5.2.6.2 Water circulating pump power rate. Watt meter or watthour meter. Error shall not exceed +/- 0.5% of reading.

## 6. Test procedures.

6.1 Cooling tower.

6.1.1 Load refrigeration machine to specified full capacity. Chilled water and condenser water temperature are measured at 10 minute intervals. The system is considered stabilized if 3 sets of data 10 minutes apart (30 minutes total) are within the tolerances as described in chiller test procedures (see Appendices 3-C, 3-D, and 3-E).

6.1.2 Turn off makeup and bleed valves.

6.1.3 Measure condenser water flow rate.

6.1.4 Measure temperature of condenser water entering and leaving cooling tower and/or condenser water temperature differential.

6.1.5 Measure entering air wet bulb temperature.

6.1.6 Measure fan power rate.

6.1.7 All measurements shall be repeated every 10 minutes for a total test run time of one hour (6 sets of data). All data shall be averaged for capacity calculations. The tolerances of measured data shall be as listed below. If any data variation is greater than listed, the test is invalidated and new test must be performed.

6.1.7.1 Water flow rates +/- 5% of specified values.

6.1.7.2 Condenser water (entering and leaving tower) +/- (0.3 °C (0.5 °F).

6.1.7.3 Entering air wet bulb temperature variation rate +/- 1.1 °C/h (2 °F/h).

6.1.7.4 Tower heat load +/- 5%.

6.2 Air cooled condenser and evaporative condenser.

6.2.1 Check head pressure control following procedures outlined in paragraph 7.1 of EXHIBIT 3-D.

6.2.2 Manipulate liquid line bypass valves directing refrigerant going through flow measuring device during test (see project specifications for piping and valve arrangement).

6.2.3 Measure condensing coil entering air temperature. This temperature shall be above 26.7 °C (80 °F).

6.2.4 The refrigeration machine shall be fully loaded. For loading procedures and system stabilization requirements, see paragraph 7.2 of EXHIBIT 3-D.

6.2.5 Data shall be taken at 10 minute intervals for a total test time of one hour (6 sets). Required data and their tolerances are as follows:

6.2.5.1 Entering air dry bulb temperature.

6.2.5.2 Refrigerant temperature at condenser inlet and outlet. The tolerance of temperature difference between this temperature and entering air dry bulb shall not be over +/- 0.1 °C (1 °F).

6.2.5.3 Refrigerant pressure at condenser inlet and outlet.

6.2.5.4 Liquid refrigerant flow rate.

6.2.5.5 Fan power rate.

6.2.5.6 For evaporative condenser only:

* Wet bulb temperature around intake air.

* Circulation pump power rate.

# 7. Calculations and comparison of performance.

## 7.1 Cooling tower.

7.1.1 Temperature range = $T_{in}$ - $T_{out}$

7.1.2 Temperature approach = $T_{out}$ - $T_{wb}$

where $T_{in}$ = condenser water entering cooling tower (hot water), average of readings
$T_{out}$ = condenser water leaving cooling tower (cold water), average of readings
$T_{wb}$ = entering air wet bulb temperature, average of readings

7.1.3 Performance criteria. The cooling tower performance from the measured values are compared with manufacturer supplied performance curves. With the same air wet bulb temperature and cooling range of the test conditions and the manufacturer's performance curve:

7.1.4 the tested approach shall be not less than the approach of the manufacturer's curve; and

7.1.5 The measured fan power rating shall not be more than the specified rating.

## 7.2 Air cooled refrigerant condenser.

7.2.1 Find enthalpy of refrigerant at condenser inlet by locating one set of inlet pressure and temperature on a pressure-enthalpy diagram (ASHRAE 1985 Handbook). If absolute pressure is needed, covert gage pressure to absolute pressure by

$P_{abs}$ = $P_{gage}$ + 101.3 kPa (all units in kPa) (For SI)

$P_{abs}$ = $P_{gage}$ + 14.696 psi (all units in psi) (For Customary)

7.2.2 Check refrigerant condition at condenser outlet by using outlet pressure and temperature. The refrigerant must be at subcooled conditions. If the refrigerant condition is not subcooled and the corresponding outside air dry bulb temperature is below the specified value, the condenser is undersized and should be rejected.

7.2.3 Similar to paragraph 7.2.1, find enthalpy of refrigerant at condenser outlet.

7.2.4 Adjust refrigerant flow rate if required (see EXHIBIT 2-B for flow rate calculations and adjustments).

7.2.5 Calculate condenser heat rejection rate.

$$Q = M (H_{in} - H_{out})$$

where $H_{in}$ = enthalpy of refrigerant at condenser inlet as calculated in 7.2.2, J/kg (Btu/lb)
$H_{out}$ = enthalpy of refrigerant at condenser outlet as calculated in 7.2.3, J/kg (Btu/lb)
M = Refrigerant mass flow rate as calculated in 7.2.4, kg/h (lb/h)
Q = Condenser heat rejection rate, J/h (Btu/h)

7.2.6 Average the 6 heat rejection rates, $Q_{avg}$. This is the condenser capacity at the test conditions.

7.2.7 Convert condenser heat rejection capacity at test conditions to that of the design conditions.

$$(Q)_{spec} = (Q)_{avg} \times \frac{(T_{cond})_{spec} - (T_{db})_{spec}}{(T_{cond})_{test} - (T_{db})_{test}}$$

where $(Q)_{spec}$ = calculated coil capacity at specified conditions, J/h (Btu/hr)
$(Q)_{avg}$ = tested coil capacity (see 7.2.6 above), J/h (Btu/h)
$(T_{cond})_{spec}$ = condensing temperature from specifications, °C (°F)
$(T_{cond})_{test}$ = saturation temperature corresponding to tested discharge pressure, °C (°F)
$(T_{db})_{spec}$ = air dry bulb temperature from specifications, °C (°F)
$(T_{db})_{test}$ = air dry bulb temperature from test, °C (°F)

7.2.8 The heat rejection rate $(Q)_{spec}$ shall not be less than 95% of the specified heat rejection capacity.

7.2.9 Calculate the average of the 6 measured fan power rates. The averaged power rate shall not be more than the specified power rate.

7.3 Evaporative condenser.

7.3.1 Find enthalpy of refrigerant at condenser inlet by locating one set of inlet pressure and temperature on a pressure-enthalpy diagram (ASHRAE 1985 Handbook). If absolute pressure is needed, covert gage pressure to absolute pressure by

$P_{abs} = P_{gage} + 101.3$ kPa (all units in kPa) (For SI)

$P_{abs} = P_{gage} + 14.696$ psi (all units in psi) (For Customary)

7.3.2 Check refrigerant condition at condenser outlet by using outlet pressure and temperature. The refrigerant must be at subcooled conditions. If the refrigerant condition is not subcooled and the corresponding outside air wet bulb temperature is below the specified value, the condenser is undersized and shall be rejected.

7.3.3 Similar to 7.3.1, find enthalpy of refrigerant at condenser outlet.

7.3.4 Adjust refrigerant flow rate if required (see EXHIBIT 2-B for flow rate calculations and adjustments).

7.3.5 Calculate condenser heat rejection rate.

$$Q = M (H_{in} - H_{out})$$

where $H_{in}$ = enthalpy of refrigerant at condenser inlet as calculated in 7.2.2, J/kg (Btu/lb)
$H_{out}$ = enthalpy of refrigerant at condenser outlet as calculated in 7.2.3, J/kg (Btu/lb)
M = Refrigerant mass flow rate as calculated in 7.2.4, kg/h (lb/h)
Q = Condenser heat rejection rate, J/h (Btu/h)

7.3.6 Average the 6 heat rejection rates, $Q_{avg}$. This is the evaporative condenser capacity at the test conditions.

7.3.7 Performance criteria.

7.3.7.1 The total heat rejection rate $Q_{avg}$ shall not be less than that shown on the manufacturer supplied curve or table at the same entering air wet bulb and saturated condensing temperature.

7.3.7.2 The average measured power rating of fan shall not be more than the specified rating.

7.3.7.3 The average measured power rating of the circulation pump shall not be more than the specified rating.

# CHAPTER 4 HEATING PLANT

1. **Scope.** This chapter provides inspection and testing procedures for heating equipment and systems. Heating equipment included in this chapter are packaged air-heating furnaces, hot-water boilers and steam boilers. Boilers may be cast-iron sectional, fire-box or Scotch-marine fire-tube type, or water-tube type. Steam boilers may be low pressure (103.4 kPa (15 psig), ASME Boiler and Pressure Vessel section IV) or medium pressure (up to 1034 kPa (150 psig), ASME Boiler and Pressure Vessel section I). Fuels for furnaces and boilers may be natural gas, oil, or electric.

## 2. Reference Standards.

a. ASME Boiler and Pressure Vessel Code - Section I (for power boilers, to operate over 103.4 kPa (15 psig) steam pressure, or over 121 °C/1103 kPa (250 °F /160 psig) hot water); Section VI (for heating boilers, to operate not over 103.4 kPa (15 psig) steam, or not over 121 °C/1103 kPa (250 °F/160 psig) hot water).

b. ASME PTC 4.1 - Steam Generating Units.

c. ASHRAE Standard 103 - Methods of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers.

d. The Hydronic Institute - Testing and Rating Standard for Heating Boilers.

e. AGA Standard - Standard for Gas-Fired Low-Pressure Steam and Hot-Water Boilers.

f. NFPA Standard 31 - Standard for the Installation of Oil Burning Equipment.

g. NFPA Standard 54 - National Gas Fuel Code.

h. NFPA Standard 85A - Standard for Prevention of Furnace Explosions in Fuel Oil- and Natural Gas-Fired Single Burner Boiler-Furnaces.

i. NFPA Standard 85B - Standard for Prevention of Furnace Explosions in Natural Gas-Fired Multiple Burner Boiler-Furnaces.

j. NFPA Standard 85D - Standard for Prevention of Furnace Explosions in Fuel Oil-Fired Multiple Burner Boiler-Furnaces.

3. **Heating System Inspection.** Boilers, furnaces, and their components shall be inspected for construction and installation to meet safety and functional requirements. See EXHIBIT 4-A for inspection procedures. See Appendix for inspection check lists.

## 4. Heating System Testing.

4.1 Boilers shall be tested in the field to meet the capacity and efficiency requirements of the contract specification. See EXHIBIT 4-B for test procedures. See Appendix for test work sheets.

4.2 Furnaces shall be tested in the field to meet the efficiency requirements of the contract specification. See EXHIBIT 4-C for test procedures. See Appendix for test work sheets.

4.3 Boilers, furnaces, and their components shall be tested for functional operations. Burners, automatic safety and capacity controls, oil preheat systems and other components must perform as prescribed in the contract specifications.

4.4 If the building load at the time of testing does not meet the specified capacity of the contract specification, means to dispose the heat generated by the test shall be provided. For hot water boilers, temporary pipe connections to load sources or building equipment cooling sources may be used. For steam boilers, applying temporary condensers to absorb discharged steam, using building equipment cooling sources, or wasting steam to the atmosphere may be used to accommodate the test. However, the test shall not cause excessively uncomfortable conditions in the building.

4.5 Operation of boilers must be preceded by heating system cleaning, boiler boil-off, and appropriate water treatment so that the heating system and boilers are protected from being contaminated.

4.6 The contract specification may allow manufacturer's factory testing in lieu of field testing. Factory testing must be witnessed by a commissioning team representative. The test intentions, test procedures, and acceptance criteria of this guide must be followed.

## EXHIBIT 4-A INSPECTION PROCEDURES FOR BOILERS AND FURNACES

1. **Scope.** The inspection procedures described in this EXHIBIT apply to packaged and field erected boilers and packaged forced-air heating furnaces. Boilers included are cast-iron, fire box, scotch marine, electric, and packaged water-tube boilers used for hot water or steam generation for HVAC systems. Energy sources for these equipment are gas, oil, or electric.

### 2. Industry standards.

a. ASME Boiler and Pressure Vessel Code specifies the requirements of construction and inspection of boilers. Section I of the Code is for power boilers and Section VI is for heating boilers. Heating boiler is defined as low pressure boiler having a maximum working pressure of 103.4 kPa (15 psig) for steam operation or a maximum working temperature of 121 °C (250 °F) and/or maximum working pressure of 1103 kPa (160 psig) for hot water operation. Power boiler is defined as medium and high pressure boiler having working pressure or temperature above those defined for low pressure boiler.

b. NFPA Standard 31 (Standard for the Installation of Oil Burning Equipment) prescribes requirements for safety in the installation of oil burners and their associated equipment used in steam, hot water, and hot air heating plants. Included are chimneys and connectors, oil storage tanks, piping, pumps, pipe fittings and accessories, and burner controls.

c. NFPA Standard 54 (National Fuel Gas Code) is a safety code which applies to the installation, inspection and testing of fuel gas systems, equipment using fuel gas and related accessories.

d. NFPA Standard 85A (Standard for Prevention of Furnace Explosions in Fuel Oil-and Natural Gas-Fired Single Burner Boiler-Furnaces) establishes standards for design, installation, operation and maintenance of single burner oil- and gas-fired boilers to contribute to safety and prevention of furnace explosions. Boiler sizes are limited to fuel input greater than 3663 kW (12.5 x $10^6$ Btu/h). Burners included are those firing natural gas only, No. 2, 4, 5, or 6 fuel oil only, simultaneous firing of gas and oil for fuel transfer, and simultaneous firing of gas and oil continuously. Emphasis is on operating and maintenance procedures, combustion control equipment, safety interlocks, alarms, trips and other related controls of boiler operation.

e. NFPA Standard 85B (Standard for Prevention of Furnace Explosions in Natural Gas-Fired Multiple Burner Boiler-Furnace) is similar to Standard 85A in its scope and purpose except that this Standard is for natural gas fired boilers only and that the number of burners are more than one. Multiple burners cause certain safety requirements to differ from those for single burner boilers. They are used mostly in field erected large boilers and their application for HVAC use are not common.

f. NFPA Standard 85D (Standard for Prevention of Furnace Explosions in Fuel Oil-Fired Multiple Burner Boiler-Furnaces) is similar to Standard 85A in its scope and purpose, except that this Standard is for oil fired boilers only and that the number of burners are more than one. The description in paragraph e. above on gas-fired multiple burners also apply to these boilers.

## 3. General inspection.

3.1 Review equipment manufacturer's instructions on start-up and operation procedures.

3.2 Give complete inspection of boiler, furnace, burner, control system, oil preheating system, and their associated equipment, including base, vibration eliminating units, associated electrical equipment, piping, ductwork, smoke stack and breeching, etc. Be sure that no mis-adjustments, damage or rusting occurred. All fastenings such as nuts, bolts, and setscrews should be inspected.

3.3 Check equipment name plates to verify equipment model and serial number. They must have the same model numbers as approved submittals.

3.4 Check for headrooms and access spaces around boiler and furnace for operation and maintenance. Design specification and manufacturer's recommended spaces must be provided. For boilers, pay special attention to heat exchanger tube replacement and cleaning spaces and access spaces to manholes and handholes. For furnaces, make sure air filter replacement space and burner service space are adequate.

3.5 Inspect heating plant (boiler room and furnace room) for possible fire hazards. The heating plant should be kept free of combustible fibers and dusts, flammable liquids, or contents susceptible to smoke or fume contamination.

3.6 Inspect heating plant ventilation openings. Check actual installation with project drawings and specifications. There shall not be blockage to combustion air inlets. If automatic dampers are specified and installed, test damper operator to be sure that dampers open before automatic burners are allowed to operate.

3.7 Verify installed pipe fittings and accessary equipment against project drawings and equipment manufacturer's recommendations for completeness and proper installation. Piping includes blow down piping, steam piping, feed water piping, gas piping (main fuel and pilot systems), and oil piping (include oil preheat system for heavy oils). Fittings and accessories include but not limit to valves, strainers, vibration elimination units, thermometer wells, piping supports, steam traps, etc.

3.8 Check piping at equipment connections. Pipes should be supported from building structure without undue stress on equipment (boiler, furnace, pump, etc.). Pay special attention to boiler safety relief valve pipes.

3.9 Make sure all gas vent pipes are terminated outdoors.

3.10 All moving parts (motors, belts, etc.) should have protection shields for personnel safety.

3.11 Check alignment of motor driven equipment. Using some simple tools such as straight edges, square edges, plumb lines, and strings yield good results. Also observe shaft and coupling for misalignment while machine is running.

3.12 Observe belt tightness of belt driven equipment. Use belt tension gage if needed. Belt tension should be as recommended by belt manufacturer.

3.13 Make sure required lubrication is complete (fan, motor, etc.).

3.14 Check for completeness of required instrumentation, including thermometers, gages, temperature and flow measuring and control devices. Required straight pipe runs and arrangements for temperature and flow measuring devices must be met.

3.15 Verify installed wiring against project drawings and manufacturer's submittals.

3.16 Check electric equipment and controls for proper grounding.

3.17 Check safety control wiring connections. All safety control switches (switches respond to temperature, pressure, flow, level, etc. to break the safety control circuit) should be connected in the ungrounded conductor.

3.18 Check all electrical connections for tightness.

3.19 Test run motors (fan, pump, air compressor, etc.) to check correct direction of rotation.

3.20 Check thermal insulation for damages and omissions. All joints should be sealed. The material, thickness, and finish should be as specified.

3.21 Check surface paint for damages and omissions. Equipment nameplates must not be painted over. Required equipment labels must be present and legible.

3.22 Note any unusual noise and vibration.

3.23 Inspections pertaining to boiler only:

3.23.1 Check water flow direction marks for check valves and flow switches.

3.23.2 All controls containing mercury switches should be checked for proper leveling.

3.23.3 If pneumatic pressure is used for boiler system controls, check control air system pressure level.

3.23.4 Inspect boiler refractory for integrate and dryness. There should be no cracks, chips, and damages. The application of refractory should be neat and plumb.

3.23.5 After boiler has been in full load operation, inspect exterior paint for discoloration spots. Discoloration spots are indications of inappropriate application of refractory material.

3.23.6 Induced draft fans must be insulated as specified.

3.23.7 make sure piping system has been cleaned before connections to boiler are made.

3.23.8 Make sure boiler is cleaned by flushing with water and boilout process is performed. Be sure boilout process is performed by the contractor or manufacturer's representative in according to manufacturer's recommendations.

3.23.9 Perform hydrostatic test to the pressure requirements of the specification. Secure Certificate of Inspection from boiler inspector. Safety valves must be removed or protected during hydrostatic test.

3.23.10 For cast iron sectional boilers during hydrostatic test, pay special attention to sealed joints, possible cracks, and defective castings which may develop leaks.

3.23.11 Make sure water treatment requirements and blowdown are maintained during operation for inspection and tests.

3.23.12 For motor starter equipped with overcurrent heaters, check heater sizes against starter manufacturer's recommendations. The recommendations are usually contained in operator's manual or posted in starter cabinet.

3.23.13 No leakage should be noted for water, oil, and steam.

3.24 Inspection pertaining to air-heating furnace only:

3.24.1 Inspect furnace duct connections for excessive air leakage.

3.24.2 Inspect furnace air filters for proper installation and cleanliness.

3.24.3 Make sure that flexible connections are installed between furnace and duct system.

**4. Boiler burner safety control inspection and tests.** Burner sequence of operations may vary between manufacturers, boiler types, heating media, pressure levels, sizes, etc. They are all designed for safe operation of boilers and are generally following certain safety codes. The Commissioning Team should be familiar with the manufacturer's operation manual before inspection. The following procedures are presented for general use:

4.1 Inspect oil nozzles, ignitors, electrodes, and other burner components.

4.2 Inspect fuel-air ratio controller, linkages, mechanical fastenings and stops for tightness and movement.

4.3 Make sure gas and oil line strainers are cleaned. Observe oil line pressure gage for erratic movement.

4.4 Before operate burners, make sure all valves and switches are in their operation positions.

4.5 Check pilot flame while draft fan is at maximum and main burner is off. The pilot should be stable. When burner switch is opened, the pilot flame should extinguish promptly. Lingering flame require checking of pilot gas valve.

4.6 Verify combustion air interlock with fuel safety valve and electric ignition. If boiler is equipped with air flow interlock, open air flow switch to verify control. If boiler is equipped with air pressure (some boilers have air pump and draft fan from the same motor and is provided with atomizing air proving switch) and damper sensing interlock, stop fan and manipulate damper position sensor to verify control. Whenever combustion air control is interrupted, the fuel safety valve and ignition must deactivate automatically.

4.7 Verify temperature interlock switches by adjusting up (for high temperature) or down (for low temperature) the temperature settings. The load contacts and indicating lights (if specified and installed) should act accordingly. This should be tested and recorded for both cut-in and cut-out positions. If calibration inaccuracies are suspected for the temperature switches, the sensing elements of the switches should be placed in temperature bath and calibrated about their recommended set points. Low temperature interlock switches are usually required in oil preheating systems for heavy heating oil boilers. High temperature interlock switches are required in hot water boilers to prevent water temperature exceeding high limits. On a 206.9 kPa (30 psi) hot water boiler the cut-out temperature should not exceed 116 °C (240 °F).

4.8 Verify pressure interlock switches by adjusting pressure settings up or down similar to temperature switches described above. In addition, reduce the pressure source (air, gas, or oil) for low pressure switches to test their responses. Low pressure interlock switches are usually required in oil supply pipes and in atomizing medium (air or steam) pipes for oil-fired burners, in gas supply pipes for gas-fired burners, and in combustion air streams to prove draft fan operation. High pressure interlock switches are required in gas pipes for gas-fired burners and in steam boilers to prevent steam pressure exceeding high limits. Some oil burners sense the differential pressure between atomizing medium (air or steam) and oil pressure to interlock main fuel line and ignition. This safety should be checked for its functioning by creating unfavorable differential pressure.

4.9 Verify automatic gas safety shutoff valve (gas fired and gas/oil fired boilers) tightness by the following procedures:

4.9.1 Connect a short flexible tubing to leakage test connection tap (located downstream of automatic safety shutoff valve between the shutoff valve and a manual gas cock) and immerse the free end of the tubing in a water cup.

4.9.2 Trip the automatic shutoff valve by removing its energy source (electricity or air pressure). The valve indicator should now agree with the valve status.

4.9.3 Close the gas cock downstream of the automatic shutoff valve. Open the pipe cock on the leakage test tap.

4.9.4 There should be no bubble observed from the flexible tubing in the water cup.

4.9.5 When the gas pipe is newly installed and is not thoroughly cleaned, the automatic shutoff valve may indicate leakage. The entire piping and valves must be cleaned and the test repeated till the valves close tight.

4.10 Test time delays and minimum or maximum time periods of safety actions by measuring actual time and compare with specified or regulation required time. Examples are:

4.10.1 When energy source (electricity or air pressure) is removed from automatic safety shutoff valve, it must close within a specified time.

4.10.2 Flame sensing relay must respond to flame failure within a specified time to trigger alarm and/or indicating light. It must also initiate control action for combustion safeguard sequences.

4.10.3 Purge timer must prevent safety shutoff valve from opening before the end of boiler purge cycle.

4.11 While the burner is on, remove the energy source (electricity or air pressure) of the automatic fuel safety valve. The fire must be out completely within specified or regulation required time. Also observe valve position indicator. The indicator must agree with the valve status.

4.12 While the burner is on, close the manual burner valve. The automatic safety shutoff valve must closed automatically within its specified or regulation required time.

4.13 Check low fire lighting-off. After pre-ignition purge and before ignition cycle, the fuel and combustion air control should be interlocked in the low fire lighting-off position.

4.14 For boilers with automatic cycling controls, check pilot flame detection controls. The main fuel shut-off valve must be closed when the pilot flame is not proven.

4.15 For larger sectional boilers with gas burners, there may be multiport main burners with multi-pilot igniters. Check electronic or thermal supervised pilot during light-off. Failure of any pilot should cause shut off of fuel to the pilots and main burners.

4.16 Check indicating lights during the entire inspection and test period to be sure that they agree with the burner control operation. Indicating lights are usually provided for:

a. Flame failure

b. Load demand

c. Fuel valve open

d. Low water

e. Draft fan.

4.17 If any lockout fails, it must be corrected and test repeated.

## 5. Boiler capacity control.

5.1 Be sure boiler water circulation is at the contract specified or manufacturer recommended minimum rate.

5.2 Be sure the oil preheating system is working properly and stable. The oil temperature supplied to the boiler should be as recommended by the manufacturer.

5.3 After boiler has been operating for a sufficient time to assure warm conditions, check fuel and air modulating controls for proper settings. The fuel air ratio at various load conditions should be maintained automatically in optimum ranges.

5.3.1 The optimum fuel-air ratio may best be checked by flue gas analysis. An Orsat apparatus may be used for flue gas analysis (see EXHIBIT 2-A for description of Orsat apparatus) with combustion product drawn from test opening in stack.

5.3.2 The proper amount of carbon dioxide in the combustion air for optimum combustion depends on the kind of fuel used. 9.5% to 10.5% for natural gas and 12.5% to 13% for fuel oil are considered reasonable. There should never be carbon monoxide measured in the flue gas.

5.3.3 The flue gas should be analyzed at various firing conditions of the boiler. If the results of combustion analysis is not satisfactory, the contractor or manufacturer's representative must readjust the settings (gas/oil pressure, gas valve, capacity controls, capacity sensing, etc., depending on the make of burner controls) and the test repeated.

## 6. Boiler safety relief valve inspection and test.

6.1 Inspect safety relief valve installations and obvious damages. The valves must not show leakage. The discharge pipes must not be supported on the valves to cause strains on the valves.

6.2 Check installed pipe sizes against project drawings. If the drawings do not show relief pipe sizes, make sure the inside diameter of the discharge pipe is equal to or larger than the safety valve outlet diameter. If manifold discharge pipes are used, the manifold inside area must be equal to or larger than the combined areas of individual pipes. Valves should be installed on boilers directly without other fittings between boilers and safety valves.

6.3 Remove safety valves during boiler cleaning and boiloff operations to protect from damaging to valve internal parts.

6.4 Note valve settings. These valves are factory set and sealed and should not be altered in the field.

6.5 Field testing of safety valves. Although safety valves are tested and adjusted in factory, they should be tested on boiler to be sure no damage occurred during storage, installation, or boiler hydrostatic testing. Testing should be done by the valve manufacturer's representative or by boiler inspector. Testing may be performed in one of the following two methods:

6.5.1 Raise boiler pressure by increasing operating pressure or by applying hydrostatic pressure to boiler (using hand pump) to the safety valve pressure setting. The valve should open.

6.5.2 While boiler is under pressure (hydrostatic pressure or operating pressure which is known by observing pressure gage), use a hand pump and hydraulic piston to lift the valve spindle until the valve is unseated. Using the boiler pressure, hand hydrostatic pressure, and the valve seat area, the valve relieve pressure may be calculated.

## 7. Boiler water level, makeup water control and low water cutoff.

7.1 Make sure water level control and low water cutoff is mounted in a plumb position.

7.2 Remove electric control box cover and inspect wiring connections, terminals and mercury switches for looseness and damages.

7.3 Test makeup water control and low water cutoff to be sure the required control actions are performed at the correct water levels.

7.3.1 The test should be done while burner is in low fire operation.

7.3.2 By observing glass gauge level, the make up water cut-in and cut-out levels may be tested by draining boiler water through drain valve or blowdown valves.

7.3.3 When makeup water line is valved off or makeup water pump disabled and the boiler is slowly drained, the point of fuel cutoff may be observed. At the moment of fuel cutoff alarm should sound and warning light activated. In no case should the water level drops below the lowest point of the water level gauge or the lowest permissible water level. For boilers equipped with dual low-water protection, each device should be tested independently. If the lowest allowable water level is reached and the burner is not cutoff automatically, the drain or blowdown valves should be closed immediately and the normal water level restored to avoid damage to the boiler.

7.3.4 For electric boilers, be sure the electric power is cutoff before water level drops below electric heating element.

7.3.5 Caution should be exercised during this test. The boiler drain and blowdown valves should always be attended so that they may be closed immediately when needed.

7.4 Inspect water gauge glass for cracks and leakage at gaskets. The gauge glass should be clean. Operate gauge column isolation valves and drain valves to make sure they function properly. After test, be sure the isolation valves are left open.

7.5 Check try-cock operations by opening and closing cocks. Compare try-cock indicated water level with that shown in gauge glass.

## 8. Other boiler inspection and tests:

8.1 Boiler blowdown.

8.1.1 Test manual blowdown operation by opening and closing blowdown valves. Blowdown valves shall not leak and blowdown pipe should be terminated as indicated in project drawings.

8.1.2 Check continuous blowdown valve for appropriate setting.

8.2 Soot blower. Oil-fired or gas/oil-fired steam water-tube boilers should be tested to assure soot blower operation.

8.2.1 Perform this test only when the boiler is operating close to full firing. Soot blowing operation during low firing may produce unfavorable conditions that could interrupt combustion.

8.2.2 Open drain valve to drain accumulated water.

8.2.3 Crack open steam valve to warm pipe up and close drain valve.

8.2.4 Adjust steam pressure to the manufacturer recommended pressure.

8.2.5 Operate soot blower as recommended by manufacturer.

8.2.6 Close steam valve and open drain valve.

8.2.7 Note any abnormal conditions.

8.3 Oil preheating system inspection (for No. 4, 5, and 6 oil).

8.3.1 Check piping and component requirements according to contract specifications and submittals.

8.3.2 Test electric oil heater thermostat cutin and cutout points by immerse its sensing element in liquid temperature bath.

8.3.3 Test hot water or steam oil heater thermostat cutin and cutout points by immerse its sensing element in liquid temperature bath.

8.3.4 Check electric heater capacity by observing oil temperature gage during startup period.

8.3.5 Test overall hot water or steam oil heater operation by observing oil temperature gage, hot water circulating pump, and steam valve actions. At any firing rate up to burner full fire, the oil temperature and pressure shall be maintained as required. The fuel oil relief valve should release excess oil to oil return line during low firing period.

8.3.6 The steam trap and condensate pipe of the steam oil heater must not be unduly hot.

8.4 Boiler breeching.

8.4.1 Check breeching for correct pitch, as specified.

8.4.2 Check cleanout doors for location, size, latching, and tightness when closed.

8.4.3 Check expansion joints for tightness.

8.4.4 Check joint of breeching entering masonry chimney for tightness.

8.4.5 Check insulation thickness and integrate.

8.4.6 Make sure test hole is provided at correct locations.

8.5 Boiler automatic recording and control instrumentation.

8.5.1 Make sure automatic recording and control instruments are as specified in contract documents and submittals.

8.5.2 Demonstrate correct calibration of all instruments. These usually include temperature (water, air, flue, etc.), pressure (steam, oil, gas, air, etc.), flue gas and other instruments as the contract specified..

8.5.3 Observe any incorrect ranges, settings, and general operations of automatic recording and control instruments.

## 9. Air-heating furnace tests.

9.1 Activate furnace heating operation by raising control thermostat setting and observe operations of components (burner, air circulation fan, combustion air fan, ignition system, vent damper, etc.). The entire on-cycle operation should be as required in project specifications and described in manufacturer's manuals. If system is equipped with thermostat having switches for cooling-heating and fan on/off, place switches at different combination of locations and observe furnace operation.

9.2 Check thermostat for correct leveling, if mercury bulb is used for electrical contacts.

9.3 Check operation of limit switch. Disconnect one leg of electric wiring at fan control switch. Insert a thermometer with sensing element at the vicinity of limit switch sensor. Then, activate furnace control. Observe burner operation. Burner should stop operation (firing) at the limit control temperature. If the bonnet temperature reaches 150 F, or reaches manufacturer's recommended limit, and firing is not stopped automatically, the limit control is defective and furnace operation must be manually stopped by turning off switch on burner control wiring. Restore fan wiring and thermostat setting after test.

## EXHIBIT 4-B TEST PROCEDURES FOR BOILERS

### 1. Scope.

The test procedures in this EXHIBIT apply to boilers used for HVAC systems. Included are cast-iron, fire box, scotch marine, electric, and packaged water tube boilers used for hot water or steam generation. Tests to confirm capacity and energy conversion efficiency are covered in this EXHIBIT. Functional tests of boilers and their auxiliaries may be found in EXHIBIT 4-A, INSPECTION PROCEDURES FOR BOILERS.

### 2. Industry standards.

a. ASHRAE Standard 103 (Methods of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers) provides procedures for determining heating seasonal efficiency of residential central furnaces and boilers using gas, oil or electric for fuel. It gives cyclic and part load testing method, test data manipulation, and calculation of seasonal performance.

b. ANSI Standard Z21.13 (AGA Standard for Gas-Fired Low-Pressure Steam and Hot-Water Boilers) covers construction and performance requirements of gas-fired steam or hot water boilers. This standard is applicable to low pressure boilers as defined in Section VI of ASME Boiler and Pressure Vessel Code and is limited to boilers of less than 3663 kW (12,500,000 Btu/h) input.

c. ASME Performance Test Code 4.1 (Steam Generating Unit) describes procedures for conducting performance tests to determine efficiency, capacity and other related characteristics of steam boilers.

d. The Hydronic Institute Testing and Rating Standard for Heating Boilers specify methods and procedures for determining performance of cast iron, steel and copper heating boilers (ASME Section IV boilers). This Standard gives test procedures and requirements for overall efficiency and combustion efficiency of boilers with 87.9 kW (300,000 Btu/h) and larger input. For boilers having less than 87.9 kW (300 Btu/h) input, the Standard use DOE test requirements.

e. See EXHIBIT 4-A INSPECTION PROCEDURES FOR BOILERS for other standards.

### 3. General.

3.1 All boilers shall be tested for output at full capacity to verify capacity requirement, except for small boilers. See contract specifications for clarification.

3.2 All boilers shall be tested for thermal efficiency at full load. Gas and oil fired boilers shall also be tested for combustion efficiencies at part loads. Two ways are generally used to test boiler thermal efficiencies for gas and oil fired boilers. They are tested by input/output method or by heat loss method. Since this guide requires testing of output at full capacity, input/output method shall be used for full capacity thermal efficiency tests.

3.3 Contract specifications usually specify the amount of energy input (in terms of fossil fuel amount or electric input amount) and the amount of energy output and its conditions, all at peak load. It may also specify the required efficiencies at different loads. Unless the specification requires otherwise, the following tests and verifications of the boiler performance shall be performed during commissioning.

3.3.1 For gas and oil fired boilers, test boiler combustion efficiencies at 25%, 50%, and 75% of specified capacity. At full load, test thermal efficiency by using input/output method. For boilers having on-off type burner controls, efficiencies shall be tested for full capacity only.

3.3.2 For gas and oil fired boilers, test and prove that the limitation of unburned combustibles is met. The amount of unburned combustibles allowed may be found in the contract specifications.

3.3.3 For electric boilers, efficiency test by input/output method is required for full load only.

3.4 The input/output method measures heat in fuel consumed and the heat output of the boiler. Boiler efficiency is calculated by:

$$\text{Efficiency (per cent)} = \frac{\text{output}}{\text{input}} \times 100$$

3.5 Flue losses account for the biggest part of gas and oil fired boiler losses. Combustion efficiency is derived from flue losses. Major effort of commissioning test should be on measuring flue losses.

3.6 Loss of unburned combustibles is minimized by gas and oil burner tuning. The contract specification gives the limitations of the amount of unburned combustibles, therefore, the commissioning team should confirm that the amount of unburned combustibles in the flue gas is below what is specified.

3.7 Since many of the steps of the boiler test procedure coincide with boiler tuneup and startup procedures which are usually performed by a factory personnel of the boiler manufacturers, the same factory personnel may be the Test Agent.

## 4. Preparation for tests.

4.1 Before the scheduled performance tests, the project contractor or manufacturer's representative has prepared the boiler in according to the recommendations of the manufacturer. The breeching and chimney should be cleaned.

4.2 Make sure that the boiler has been cleaned. Oil, grease, and foreign matter must be chemically cleaned and flushed. Water treatment specialist should be consulted as to the cleaning compounds and application procedures for cleaning boiler and treatment of feed water (For requirement of water treatment, consult contract specification). In most cases the building piping system is connected to the boiler to be commissioned. The entire system shall be cleaned. Safety relief valves must be protected during cleaning.

4.3 Make sure that boiler and auxiliaries (burners, pumps, fans, etc.) are adjusted for operation.

4.4 Make sure that boiler has been boiled out. Water treatment specialist should be consulted for selection of chemical compounds and boil-out procedures. Safety relief valves must be protected.

4.5 Most boiler inspection items should be performed and requirement satisfied before performance tests are attempted. See EXHIBIT 4-A for inspection requirements.

4.6 Final adjustments by construction contractor or manufacturer's representative must be performed before commencing performance tests.

4.7 For boilers requiring preheating of heavy oil, the oil preheat system must be in normal operating conditions before tests.

4.8 During capacity and efficiency tests (see Paragraph 6. below), the heating energy produced by the boiler must be absorbed by building air handling and/or other equipment such as temporary heat exchangers or steam condensers with cooling medium provided from building cooling system or temporary cooling equipment. These building equipment should be prepared and ready for operation before boiler tests. Steam boilers may be arranged to waste steam to the atmosphere if the steam produced can be safely piped to outside the heating plant. The construction contractor should have complete plan and preparation for this exercise. Overheating of building occupied spaces should be avoided.

## 5. Instrumentation.

5.1 Make sure that all instrumentation are in good working orders and are in calibration. See Chapter 2 BASIC MEASUREMENT for calibration of instruments.

5.2 Instruments required by the contract specification and/or installed by the contractor or boiler manufacturer may be used for performance tests, if they meet the accuracy and calibration requirements of this guide.

5.3 The required measurement, minimum accuracies, and measurement precautions of instruments are given below:

5.3.1 Temperature.

5.3.1.1 Flue temperature. The total measurement system error shall not exceed +/- 2.8 °C (5 °F). Most temperature measurement instruments suitable for the temperature range of up to 538 °C (1000 °F) may satisfy this requirement. The selection of instruments depends mainly on how practical they can be used in the field for the size of the boiler.

5.3.1.2 Combustion air temperature. The total measurement error shall not exceed +/- 0.6 °C(1 °F).

5.3.1.3 Steam temperature and feed water temperature. The total measurement error shall not exceed +/- 0.6 °C (1 °F).

5.3.1.4 Hot water (for hot water boiler) inlet and outlet temperature. The total measurement error shall not exceed +/- 0.3 °C (0.5 °F). A single measurement of temperature differential (water outlet temperature minus water inlet temperature) is preferred than measuring individual inlet and outlet temperatures. The total measurement error for differential temperature measurement shall not exceed +/- 0.3 °C (0.5 °F).

5.3.2 Flue gas concentration measurement. Orsat apparatus may be used to measure carbon dioxide, oxygen, and carbon monoxide from the same gas sample. Portable oxygen, carbon dioxide, or carbon monoxide monitors may be used to measure individual gas components in the flue gas.

5.3.2.1 Orset apparatus. See EXHIBIT 2-A COMMONLY USED FIELD TEST INSTRUMENTS. Be certain that the person conducting flue gas measurement with Orsat apparatus is experienced in its use and the chemical reagents are fresh.

5.3.2.2 Oxygen monitor. The total measurement error shall not exceed +/- 0.1 percentage points.

5.3.2.3 Carbon dioxide monitor. The total measurement error shall not exceed +/- 0.1 percentage points.

5.3.2.4 Carbon monoxide monitor. The total measurement error shall not exceed +/- 0.01 percentage points.

5.3.2.5 Gas concentration monitors must be calibrated with standard gas with concentration close to that of the flue gas.

5.3.3 Gas flow rate measurement. Use calibrated gas flow meter. There may be gas flow meters installed by the gas company. Check if the meter is dedicated for the boiler to be tested. If not, gas use to other boiler of appliances need to be turned off during this test. Measurement error shall not exceed 1% of flow.

5.3.4 Oil flow rate measurement. Use positive displacement meter (see EXHIBIT 2-A COMMONLY USED FIELD TEST INSTRUMENTS). The meter must be calibrated for the kind of oil and the temperature at the measuring location. Depending on the piping arrangement of the burner (with or without oil return, oil heating equipment location in relationship to the burner, etc.), the location of the meter should be closely examined so that the exact amount of oil consumed by the burner may be recorded. The measurement error shall not exceed 1%.

5.3.5 Steam flow rate and hot water flow rate. The total measurement error shall not exceed +/- 3%. It is important to check the primary element location for good data. If pipe length does not meet those given in Chapter 2, flow straightener should be used.

5.3.6 Feed water flow to steam boilers may be intermittent. A positive displacement meter with flow readout should be used. The measurement error shall not exceed +/- 1%.

5.3.7 Electric usage for heating element of electric boiler shall be measured by Watt-hour meter with total measurement error not to exceed 0.5%.

5.3.8 Pressure.

5.3.8.1 Gas pressure for gas-fired boiler at a location where the gas flow rate is measured. The measurement error shall not exceed +/- 50 Pa (0.2 in. of water).

5.3.8.2 Steam pressure for steam boiler. Measurement error shall not exceed +/- 0.5% of reading.

5.3.8.3 Barometric pressure. Measurement error not to exceed +/- 338 Pa (0.1 in of Hg).

5.3.8.4 Pressure at flue pipe. Measurement error not to exceed 12.4 Pa (0.05 in. of water).

## 6. Test Procedures. (see Section 3. for required tests)

6.1 Gas and oil-fired boilers.

6.1.1 The tests to confirm the boiler capacity and thermal efficiency are essentially steady state tests at various loads.

6.1.2 After the boiler has been warmed up, the boiler capacity shall be adjusted to 25% of the full load capacity as required in the contract specification and the burner capacity control shall be set to manual. The measurement of load level is done by measuring fuel input flow rate and the heating value of the fuel or by measuring the output rate of the boiler (Measuring output at 25% capacity is for hot water boiler only. Measuring steam output at this low capacity is generally not advisable). The actual running capacity shall be within +/- 3% of the calculated capacity (full capacity input or output as specified times 25%).

6.1.3 The building air handling and/or other cooling equipment may need to be adjusted during the test to provide steady and approximately correct load.

6.1.4 Test data shall be taken after boiler has been running at steady state conditions for at least 30 minutes. Steady state conditions of the boiler operation is defined by measuring the temperature of flue, entering water, and leaving water (for hot water boiler) or steam pressure (for steam boiler). All these temperatures shall not vary over 5.6 °C (10 °F) and the pressure shall not vary over 13.8 kPa (2 psi) during a 30 minute period with three set of measurements at 15 minute intervals.

6.1.5 Test data required are listed below (See later sections for detailed measurement requirements). Three sets of test data shall be taken at 15 minute intervals and they shall be arithmetically averaged for capacity and efficiency calculations.

6.1.5.1 Measure carbon monoxide concentration (volumetric) of flue gas. If the concentration is higher than that allowed in the contract specification, the test shall be stopped and the burner retuned. If Orsat apparatus is used for measuring gas concentration levels, the Orsat procedure requires that carbon dioxide and oxygen levels are measured before carbon monoxide.

6.1.5.2 Measure carbon dioxide or oxygen concentration level of flue gas.

6.1.5.3 Measure flue gas temperature.

6.1.5.4 For gas-fired units, record gas flow rate, gas temperature and pressure at burner inlet of gas train.

6.1.5.5 For oil-fired units, record oil flow rate, oil temperature and pressure at burner inlet.

6.1.5.6 For hot water boilers, measure and record water inlet and outlet temperature. If differential temperature measurement is chosen, measure and record differential temperature.

6.1.5.7 For steam boilers measure and record feed water temperature, steam temperature, and steam pressure. Check the state of steam by comparing steam temperature and pressure against steam tables. Steam must be dry. If the steam is wet, the boiler must be rejected.

6.1.5.8 Measure and record barometric pressure.

6.1.5.9 Measure and record combustion air temperature.

6.1.6 During the 30 minute test period there shall be no blowdown or soot-blowing.

6.1.7 Same procedures outlined in paragraphs 6.1.2, 6.1.3, 6.1.4, 6.1.5, and 6.1.6 above shall be repeated at 50%, and 75% load. For the 100% load (full load) tests, the burner fuel control setting shall be at its highest level. In addition to the measurements as required for part load tests, hot water flow rate (for hot water boilers) or steam flow rate (for steam boilers), shall be measured at 100% load test.

6.1.8 Measurement details.

6.1.8.1 Heating values of fuel. Higher heating values of fuels are required for combustion efficiency calculations.

* Gas company supplying the fuel can provide heating value data for the time of the test. Heating values are usually quite steady for a short period such as for boiler testing. Make sure the heating value data error from the gas company is less than 1%.

* Oil-fired units need laboratory calorimetry tests to determine the higher heating values of the oil. Sample oil should be send to creditable laboratories for the test. Be certain that the oil used for the performance test is the same oil for heating value determination and that the laboratory conducting this service can keep the measurement error below 1%.

6.1.8.2 Flue gas temperature.

* Flue temperature should be measured at the boiler flue outlet close to the boiler to avoid errors caused by air leakage. For gas-fired boilers having draft hoods or diverters, temperature should be measured upstream of hoods and diverters. If temperature sensor must be located in breeching, examine any possibility of air leakage between boiler flue outlet and the temperature taking location. The temperature measuring section of the flue pipe or breeching shall be insulated with foil-faced 0.051 m (2 in.) thick mineral fiber or other high temperature insulation. The length of insulated section shall not be less than three times of the flue or breeching diameter.

* For small boilers with a short smoke path, pay attention to the location of the temperature sensing elements so that the sensors do not sense the direct radiation effect of the fire.

* In order to reduce the effect of flue gas temperature stratification, temperature traverse shall be measured at a rate of one measurement per one square foot of cross sectional area on the measurement plane. The measurement data shall be arithmetically averaged to represent average flue temperature.

6.1.8.3 Flue gas component measurement.

* Flue gas sampling. If flue gas sampling line is used, it should be made as short as possible and slope in the direction of flow. Also check the following:

** The material of the sampling tube must be suitable for the temperature of the flue gas.

** Check possible leakage of the tube at tube fittings and around sampling holes at flue pipe or breeching. Make certain that the sample gas represents the true flue gas.

** If metal tube is used, draw flue sample for at least 10 minutes through the tube before the sample is used for gas analysis, so that the chemical reaction of the inner tube surface does not affect the results.

* Flue gas sensor.

** When flue gas sensor is directly placed in flue line, check flue opening around sensor for possible air leakage.

** Flue sensing instrument installed as part of combustion sensing and control device may be used to monitor flue composition for commissioning purpose.

** Portable or permanent sensing instrument must be calibrated with standard gas for the entire instrument range.

* Flue gas measuring location shall be as close to flue gas temperature measuring location as possible.

* Flue gas component measurement should follow immediately the flue temperature measurement given in paragraph 6.1.4.3 above.

(e) Combustion air temperature measurement. One measurement shall be made in front of the boiler combustion air intake approximately 1.2 m (4 ft) from the boiler. A radiation shield shall be used between the temperature sensor, the boiler, and other high surface temperature equipment.

6.2 Electric boilers.

6.2.1 Electric boilers shall be tested for full capacity and for efficiency at full load by input/output method.

6.2.2 The building air handling and/or other equipment may need to be adjusted during the test to provide steady and approximately correct load.

6.2.3 Test data shall be taken after boiler has been running at steady state conditions for at least 30 minutes. Steady state conditions of the boiler operation is defined by measuring the temperature of entering water and leaving water (for hot water boiler) or entering water and steam pressure (for steam boiler). All these temperature shall not vary over 5.6 °C (10 °F) during a 30 minute period with three set of measurements at 15 minute intervals.

6.2.4 Test data required are listed below.

6.2.4.1 Measure and record electricity input power rate of heating elements and voltages of all three phases.

6.2.4.2 For hot water boilers, measure and record water inlet and outlet temperature.

6.2.4.3 For steam boilers measure and record water inlet temperature and steam pressure.

6.2.4.4 Measure and record hot water (for hot water boiler) or steam (for steam boiler) flow rate.

## 7. Calculations and rate performance.

### 7.1 Boiler capacity.

7.1.1 Boiler capacity is calculated from 100% capacity test data.

7.1.1.1 Steam boiler.

$$(q)_{out} = M\ (H_s - H_w)$$

7.1.1.2 Hot water boiler.

$$(q)_{out} = M\ (H_{out} - H_{in})$$

Symbols: $(q)_{out}$ = boiler output, W (Btu/h)
$M$ = mass flow rate of steam or hot water, kg/s (lb/h), see SE-37, 39, 41, or 43 of EXHIBIT 2-B
$H_s$ = enthalpy of steam, J/kg (Btu/lb), locate in steam table knowing temperature and pressure
$H_w$, $H_{out}$, $H_{in}$ = enthalpy of feed water, hot water supply, and hot water return, respectively, locate in steam tables knowing their respective temperature

7.1.2 Boiler capacity shall not be less than specified in the contract specifications.

### 7.2 Boiler heat input.

7.2.1 For gas-fired units. Convert measured gas volume flow rate to standard conditions. Standard conditions for gas is usually at 15 °C (60 °F) and 101.3 kPa (30 in. of Hg). This standard conditions should be confirmed with gas supplier who provides gas heating values.

$$Q_s = Q_m \left(\frac{P_m + P_b}{101.3}\right) \left(\frac{15 + 273}{T_m + 273}\right) \qquad \text{(For SI)}$$

$$Q_s = Q_m \left(\frac{P_m + P_b \times 13.57}{30 \times 13.57}\right) \left(\frac{60 + 460}{T_m + 460}\right) \qquad \text{(For Customary)}$$

where: $Q_s$ = volume flow rate of gas at standard conditions, $m^3/s$ ($ft^3/h$)
$Q_m$ = measured flow rate of gas, $m^3/s$ ($ft^3/h$)
$P_m$ = measured gas pressure, kPa (in. of water)
$P_b$ = barometric pressure, kPa (in. of Hg)
$T_m$ = measured gas temperature, °C (°F)

Then, calculate the heat input to the boiler:

$$(q)_{in} = Q_s \times (HHV)_g$$

where: $(q)_{in}$ = heat input rate, W (Btu/h)
$(HHV)_g$ = higher heating value of gas, J/m$^3$ (Btu/ft$^3$)

7.2.2 For oil-fired units.

$$Q_s = Q_m \times [1 - (T_m - 15) \times V_f] \qquad \text{(For SI)}$$

$$Q_s = Q_m \times [1 - (T_m - 60) \times V_f] \qquad \text{(For Customary)}$$

$$(q)_{in} = Q_s \times (HHV)_o$$

where: $Q_s$ = volumetric oil flow rate at 15 °C (60 °F), m$^3$/s (gph)
$Q_m$ = measured volumetric flow rate of oil, m$^3$/s (gph)
$T_m$ = measured oil temperature at flow meter, °C (°F)
$V_f$ = specific volume factor to adjust volume change due to temperature, if not available from oil test lab, use 0.00068 per °C (0.00038 per °F)
$(q)_{in}$ = heat input rate, W (Btu/h)
$(HHV)_o$ = higher heating value of oil as supplied by testing lab, J/m$^3$ (Btu/gal)

7.2.3 For electric units. Calculate heat input to electric elements of boiler from measured electric energy:

$$(q)_{in} = W \qquad \text{(For SI)}$$

$$(q)_{in} = W \times 3413 \qquad \text{(For Customary)}$$

where: (q)in = heat input rate, W (Btu/h)
W = watt meter reading, W

7.3 Boiler thermal efficiency at full load.

7.3.1 $$\text{eff (in \%)} = \frac{(q)_{out}}{(q)_{in}} \times 100$$

7.3.2 Boiler thermal efficiency at full load shall not be lower than that required in the contract specification.

7.4 Combustion efficiency at part loads (for gas and oil fired boilers only).

7.4.1 Flue losses $(q)_f$. Flue losses may be obtained by using charts supplied by burner manufacturers or other professional/trade associations. Calculate the temperature difference between the temperature and combustion air temperature. The flue loss is obtained from the charts as a function of the measured percent of O2 (or $CO_2$) at the measured temperature difference.

7.4.2 The combustion efficiency is represented by:

eff (in %) = 100 - (Flue loss in percent)

7.4.3 Boiler combustion efficiencies at 25%, 50%, and 75% shall not be less than those required in the contract specifications.

## EXHIBIT 4-C TEST PROCEDURES FOR AIR-HEATING FURNACES

1. **Scope.** The test procedures in this EXHIBIT apply to gas, oil, or electric fired packaged furnaces used for building air heating systems. Tests to confirm capacity and energy conversion efficiency are covered in this EXHIBIT. Functional tests of furnaces may be found in EXHIBIT 4-A, INSPECTION PROCEDURES FOR BOILERS AND FURNACES.

### 2. Industry standards.

a. ASHRAE Standard 103-1988R (Methods of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers) provides procedures for determining heating seasonal efficiency of residential central furnaces and boilers using gas, oil or electric for fuel. It gives cyclic and part load testing method, test data manipulation, and calculation of seasonal performance.

b. ANSI Z21.7 (Standard for Gas-Fired Warm Air Furnaces) gives the minimum construction, safety, and performance requirements for gas furnaces.

c. See EXHIBIT 4-A INSPECTION PROCEDURES FOR BOILERS AND FURNACES for other standards.

### 3. General.

3.1 All furnaces shall be tested for output at full capacity to verify capacity requirements, except certain small furnaces specifically exempt by contract specifications. Check contract specifications for requirement.

3.2 All fossil-fuel furnaces shall be tested for combustion efficiency at full load.

3.3 Two ways are generally used in the industry to test furnace efficiencies. They are tested by input/output method or by heat loss method. Since air heating furnaces in federal building are relatively small as compared to other heating equipment (boilers), commissioning tests should be concentrated on verifying capacity and combustion efficiency.

3.3.1 Gas and oil fired furnaces shall be tested for combustion efficiency (not thermal efficiency) at full capacity by using heat loss method.

3.3.2 Electric furnaces need not be tested for combustion efficiency.

3.4 The input/output method measures heat in fuel consumed and the heat output of the furnace. Furnace efficiency is calculated by:

$$\text{Efficiency (percent)} = \frac{\text{output}}{\text{input}} \times 100$$

3.5 Combustion efficiency is calculated by:

$$\text{efficiency (percent)} = [1 - (\text{sensible loss of dry gas}) - (\text{hydrogen loss})] \times 100$$

Hydrogen loss is the loss of water vapor of combustion air.

3.6.1 Flue losses account for the biggest part of furnace losses. Major effort of commissioning test should be on measuring flue losses.

3.6.2 Furnace surface losses are small compared to stack losses. Therefore, it is ignored in commissioning tests for furnaces.

3.6.3 Loss of unburned combustibles is minimized by burner tuning. The contract specification gives the limitations of the amount of unburned combustibles, therefore, the commissioning team should confirm that the amount of unburned combustibles in the flue gas is below what is specified.

## 4. Preparation for tests.

4.1 Before the scheduled performance tests, the project contractor or manufacturer's representative should have prepared and tuned the furnace in according to the recommendations of the manufacturer.

4.2 Make sure that furnace and air filters are cleaned, air circulation fan (and combustion air fan, if provided) are adjusted correctly and oiled, and burner are tuned for operation.

4.3 All furnace inspection items should be performed and requirement satisfied before performance tests are attempted. See EXHIBIT 4-A for inspection requirements.

4.4 The commissioning team should coordinate with the contractor and building user to arrange appropriate time for testing so that the building occupants will not be subjected to overheating conditions.

## 5. Instrumentation.

5.1 Make sure that all instrumentation are in good working orders and are in calibration. See Chapter 2 BASIC MEASUREMENT for calibration of instruments.

5.2 Instruments required by the contract specification and/or installed by the contractor or manufacturer may be used for performance tests, if they meet the accuracy and calibration requirements of this guide.

5.3 The required measurement, minimum accuracies, and measurement precautions of instruments are given below:

5.3.1 Temperature.

5.3.1.1 Flue temperature. The total measurement system error shall not exceed +/- 2.8 ° (5 °F). Most temperature measurement instruments suitable for the temperature range of up to 538 °C (1000 °F) may satisfy this requirement.

5.3.1.2 Combustion air temperature. The total measurement error shall not exceed +/- 0.6 °C (1 °F).

5.3.1.3 Supply air and return air temperature. The total measurement error shall not exceed +/- 0.3 °C (0.5 °F). Direct measurement of temperature differential (supply air temperature minus return air temperature) is preferred than measuring individual supply and return temperatures. The total measurement error for differential temperature measurement shall not exceed +/- 0.3 °C (0.5 °F).

5.3.2 Flue gas component measurement. Orsat apparatus may be used to measure carbon dioxide, oxygen, and carbon monoxide from the same gas sample. Portable oxygen, carbon dioxide, or carbon monoxide monitors may be used to measure individual gas components in the flue gas.

5.3.2.1 Orsat apparatus. See EXHIBIT 2-A COMMONLY USED FIELD TEST INSTRUMENTS. Be certain that the person conducting flue gas measurement with Orsat apparatus is experienced in its use and the chemical reagents are fresh.

5.3.2.2 Oxygen monitor. The total measurement error shall not exceed +/- 0.1 percentage points.

5.3.2.3 Carbon dioxide monitor. The total measurement error shall not exceed +/- 0.1 percentage points.

5.3.2.4 Carbon monoxide monitor. The total measurement error shall not exceed +/- 0.01 percentage points.

5.3.2.5 Gas concentration monitors must be calibrated with standard gas with concentration close to that of the flue gas.

5.3.3 Furnace air flow rate. Use pitot traverse and water manometer to measure either supply or return air flow rate. The measurement error shall not exceed +/- 5 percent of the quantity measured.

5.3.4 Electric usage for heating element of electric furnace. The measurement error of watt-hour meter shall not exceed 1%.

5.3.5 Pressure at flue pipe. Measurement error not to exceed 12.4 Pa (0.05 in. of water).

## 6. Test Procedures for full load capacity and combustion efficiency. (see paragraph 3. above for required tests)

6.1 The test to confirm the furnace capacity and combustion efficiency is conducted under steady state operation. Turn thermostat up for about 5.6 °C (10 °F) to initiate furnace operation. Measure the supply air temperature at 5 minute intervals. If the variation of 3 measurements are within 1.7 °C (3 °F), the system is considered stabilized and test data may be collected.

6.2 Test data required are listed below (See later sections for detailed measurement requirements). Three sets of test data shall be taken at 15 minute intervals and they shall be arithmetically averaged for capacity and efficiency calculations.

6.2.1 Gas and oil-fired furnaces.

6.2.1.1 Measure carbon monoxide concentration (volumetric) of flue gas. If the concentration is higher than that allowed in the contract specification, the test shall be stopped and the burner retuned. If Orsat apparatus is used for measuring gas levels, carbon dioxide and oxygen levels are measured before carbon monoxide.

6.2.1.2 Measure carbon dioxide or oxygen concentration level of flue gas.

6.2.1.3 Measure flue gas temperature.

6.2.1.4 Measure room temperature where the furnace is situated. This temperature will be used as combustion air temperature unless combustion air is ducted to unit.

6.2.1.5 Measure supply air temperature.

6.2.1.6 Measure return air temperature.

6.2.1.7 Measure return air dew point or relative humidity.

6.2.1.8 Measure barometric pressure.

6.2.1.9 Measure air flow rate.

6.2.2 Electric furnaces.

6.2.2.1 Measure room temperature where the furnace is situated.

6.2.2.2 Measure supply air temperature.

6.2.2.3 Measure return air temperature.

6.2.2.4 Measure return air dew point or relative humidity.

6.2.2.5 Measure barometric pressure.

6.2.2.6 Measure air flow rate.

6.2.3 Measurement details.

6.2.3.1 Heating values of fuel. Higher heating values of fuels are required for combustion efficiency calculations.

* Gas company supplying the fuel can provide heating value data for the time of the test. Heating values are usually quite steady for a short period such as for furnace testing. Make sure the heating value data error from the gas company is less than 1%.

* Oil-fired units need laboratory calorimetry tests to determine the higher heating values of the oil. Sample oil should be send to creditable laboratories for the test. Be certain that the oil used for the performance test is the same oil for heating value determination and that the laboratory conducting this service can keep the measurement error below 1%.

6.2.3.2 Flue gas temperature.

* Flue temperature should be measured at the furnace flue outlet close to the furnace to avoid errors caused by air leakage. For gas-fired furnaces having draft hoods or diverters, temperature should be measured upstream of hoods and diverters. If temperature sensor must be located in breeching, examine any possibility of air leakage between furnace flue outlet and the temperature taking location. The temperature measuring section of the flue pipe or breeching shall be insulated with foil-faced 0.051 m (2 in.) thick mineral fiber or other high temperature insulation. The length of insulated section shall not be less than three times of the flue or breeching diameter.

* Pay attention to the location of the temperature sensing elements. The sensors shall not sense the direct radiation effect of the fire.

* In order to reduce the effect of flue gas temperature stratification, three measurements at different locations of the same flue cross-sectional plane shall be measured. The measurement data shall be arithmetically averaged to represent average flue temperature.

6.2.3.3 Flue gas component measurement.

* Flue gas sampling. If flue gas sampling line is used, it should be made as short as possible and slope in the direction of flow. Also check the following:

** The material of the sampling tube must be suitable for the temperature of the flue gas.

** Check possible leakage of the tube at tube fittings and around sampling holes at flue pipe or breeching. Make certain that the sample gas represents the true flue gas.

** If metal tube is used, draw flue sample for at least 10 minutes through the tube before the sample is used for gas analysis, so that the chemical reaction of the inner tube surface does not affect the results.

* Flue gas sensor.

** When flue gas sensor is directly placed in flue line, check flue opening around sensor for possible air leakage.

** Portable or permanent sensing instrument must be calibrated with standard gas for the entire instrument range.

* Flue gas measuring location shall be as close to flue gas temperature measuring location as possible.

* Flue gas component measurement should follow immediately the flue temperature measurement given in paragraph 6.2.3.2 above.

6.2.3.4 Furnace room air temperature measurement. One measurement at approximately 1.2 m (4 ft) in front of the furnace shall be made. A radiation shield shall be used between the temperature sensor and the furnace.

6.2.3.5 Supply and return air temperature. See EXHIBIT 2-C STANDARD TEST PROCEDURES for details.

6.2.3.6 Air flow rate. See EXHIBIT 2-C STANDARD TEST PROCEDURES for details.

**7. Calculations and rate performance.** (See EXHIBIT 2-B for Standard Equations of parameter calculations)

7.1 Furnace capacity.

$$(q)_{out} = \frac{Q}{v}(H_{out} - H_{in})$$

Symbols:

$(q)_{out}$ = furnace capacity, W (Btu/h)
Q = volume flow rate of air, $m^{3/s}$ ($ft^3/m$)
v = specific volume of air (average of inlet and outlet temperature), $m^3/kg$ ($ft^3/lb$)
$H_{out}$ = enthalpy of air at outlet, J/kg (Btu/lb)
$H_{in}$ = enthalpy of air at inlet, J/kg (Btu/lb)

7.2 Furnace capacity shall not be less than specified in the contract specifications.

7.3 Combustion efficiency (required for gas or oil fired furnaces at full load only).

7.3.1 Sensible flue loss $(q)_f$. Sensible flue losses may be obtained by either using equations or charts.

7.3.1.1 When calculation is preferred, the following equations shall be used:

$$R = A + \frac{B}{X}$$

$$L = \frac{100}{HHV}\left([(1 + AF)\ (CF(i) + AF\ (R - 1)\ (CA(i))]\right.$$

$$\left.\times\ [(T_{gas} + 460)^i - (T_{air} + 460)^i]\right)$$

where: R = ratio of combustion air to stoichiometric air, dimensionless
X = measured concentration of $CO_2$ (by volume, %)
HHV = higher heating value of fuel, Btu/lb
$T_{gas}$ = flue gas temperature, °F
$T_{air}$ = combustion air temperature, °F
CA(1) = $2.5462121 \times 10^{-1}$
CA(2) = $-3.0260126 \times 10^{-5}$
CA(3) = $2.7608571 \times 10^{-8}$

$CA(4) = -7.4253321 \times 10^{-12}$
$CA(5) = 6.4307377 \times 10^{-16}$
i = an index, 1 through 5
A, B, AF, CF = constants from following table:

| | A | B | AF |
|---|---|---|---|
| Natural gas | 0.09194 | 10.96 | 14.56 |
| No. 2 oil | 0.0679 | 14.22 | 14.56 |

| | CF(1) | CF(2) | CF(3) |
|---|---|---|---|
| Natural gas | $2.5949478 \times 10^{-1}$ | $-4.9475802 \times 10^{-6}$ | $1.3885838 \times 10^{-8}$ |
| No. 2 oil | $2.4361163 \times 10^{-1}$ | $3.6702686 \times 10^{-6}$ | $8.7098897 \times 10^{-9}$ |

| | CF(4) | CF(5) |
|---|---|---|
| Natural gas | $-2.8059994 \times 10^{-12}$ | $3.7682444 \times 10^{-17}$ |
| No. 2 oil | $-1.3619019 \times 10^{-12}$ | $-1.5029209 \times 10^{-16}$ |

(b) When using charts is preferred, calculate the temperature difference between the flue temperature and the combustion air temperature. Using this value and the R value as calculated in the previous paragraph on sensible heat loss charts (charts 1 through 4), the sensible heat loss may be directly read. The loss of water vapor of combustion product (also called hydrogen loss) is 9.55% for natural gas and 6.50 for No. 2 oil. The total combustion loss is the sum of sensible loss and hydrogen loss.

6.4 Furnace combustion efficiency shall not be less than that specified in the construction specifications.

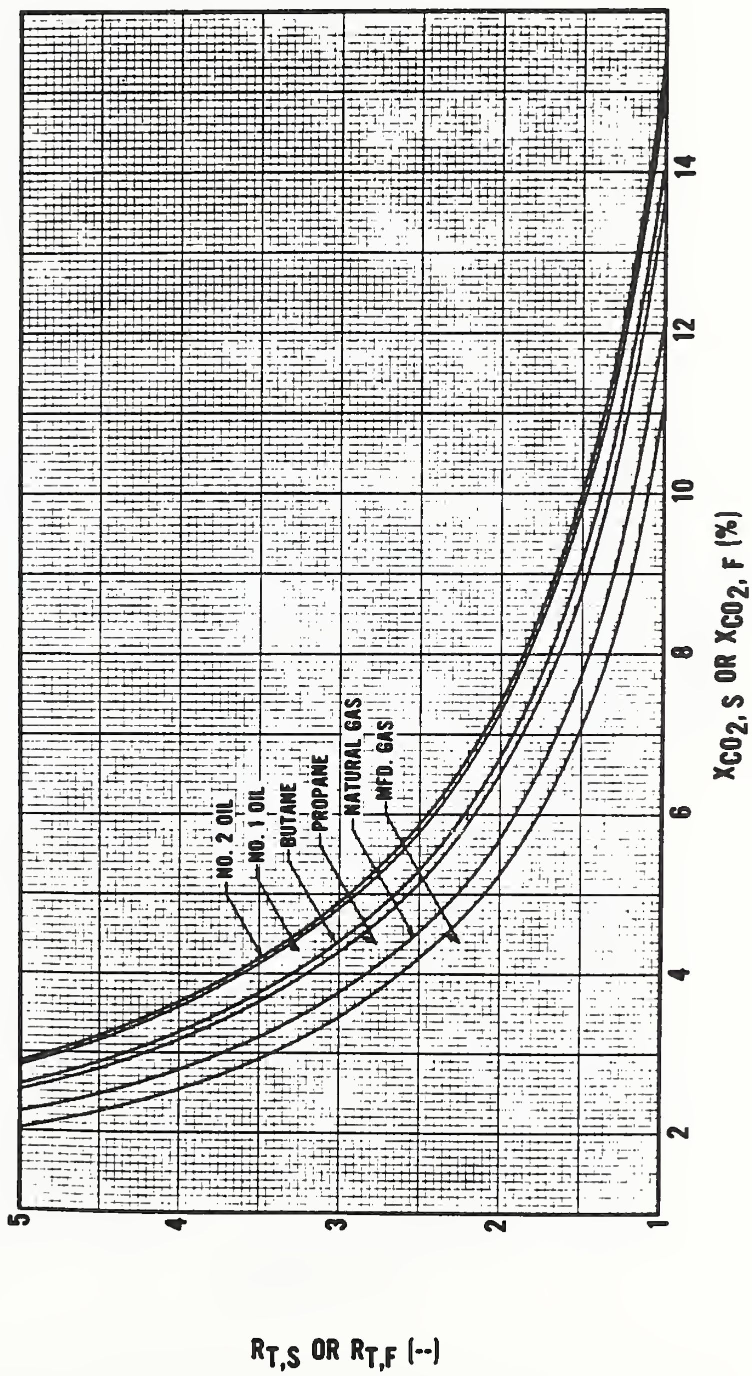


Chart 1. Ratio of Total Combustion to Stoichiometric Air

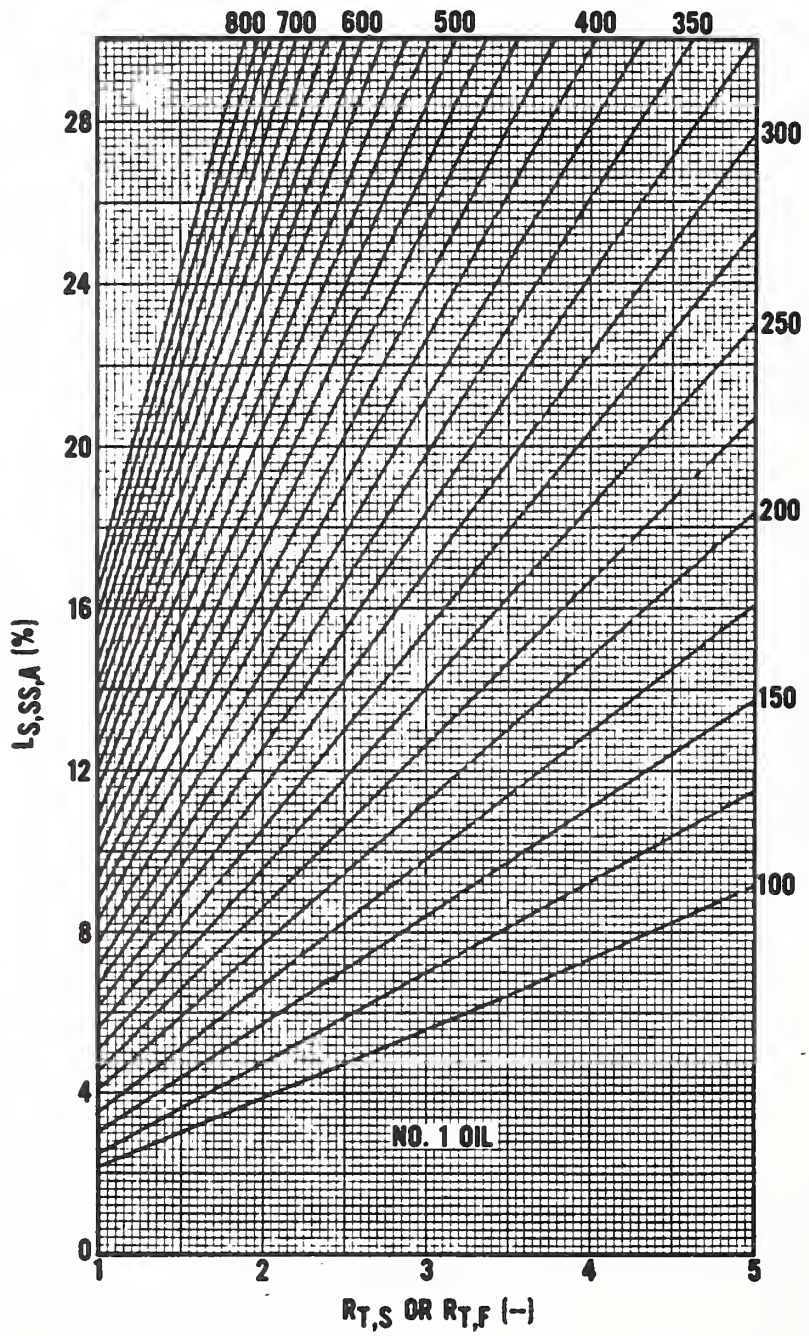


Chart 2. Steady-State Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (No. 1 Oil)

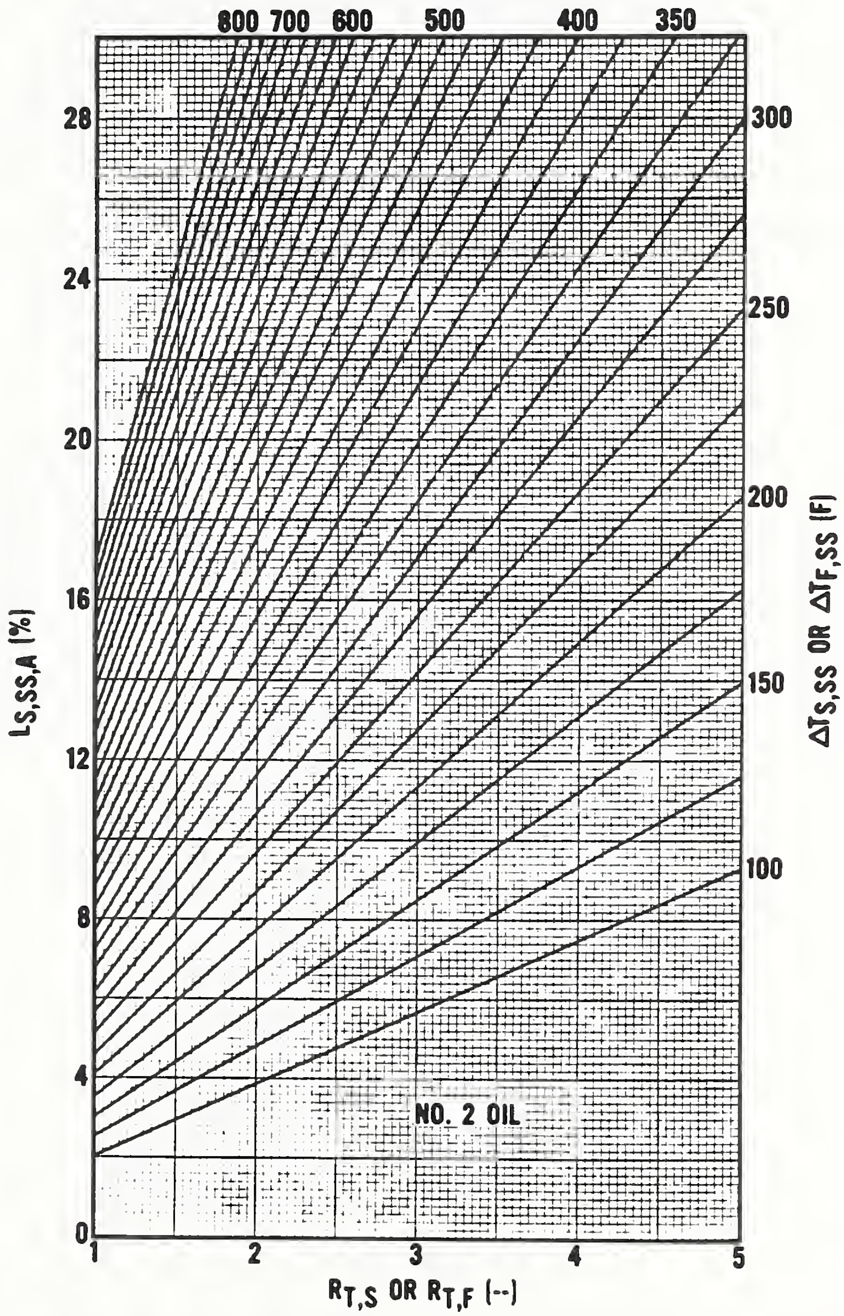


Chart 3. Steady-State Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (No. 2 Oil)

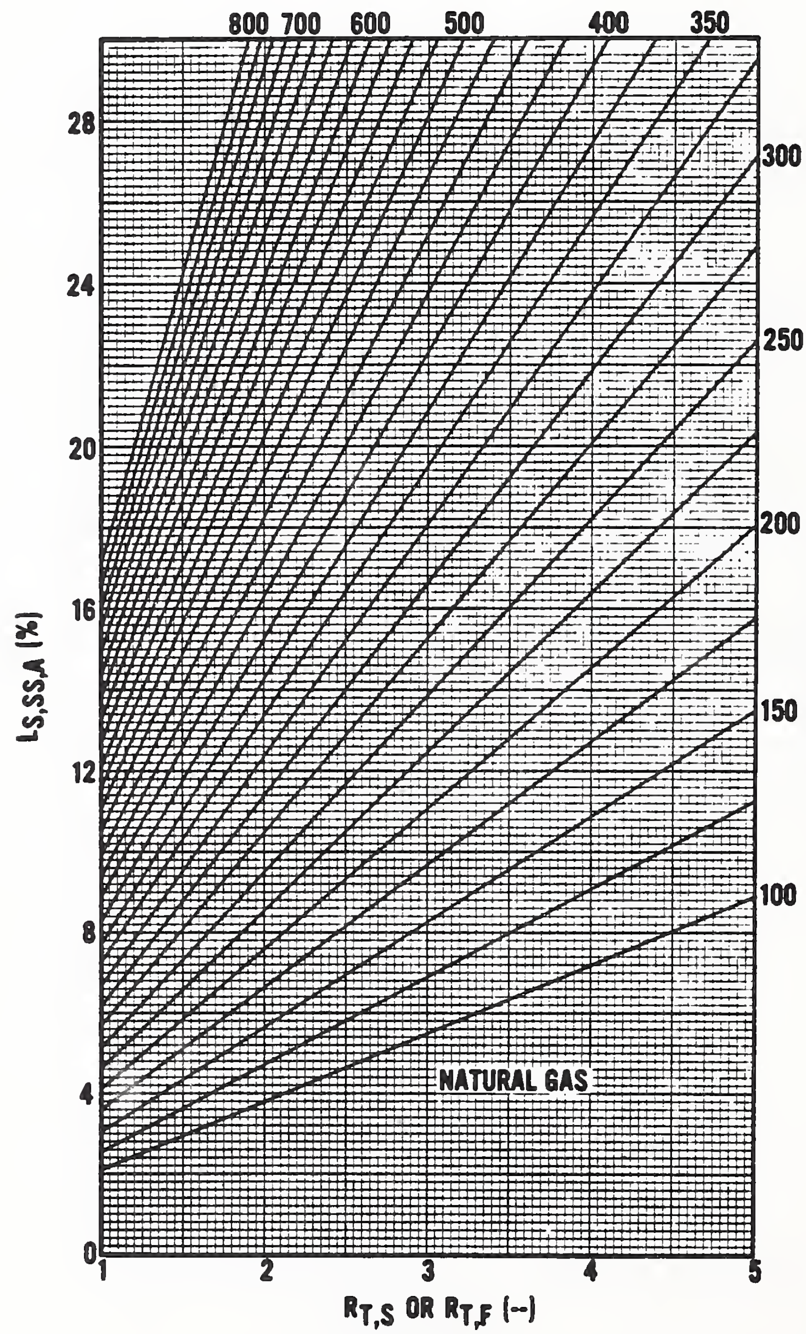


Chart 4. Steady-State Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (Natural Gas)

# CHAPTER 5 AIR HANDLING EQUIPMENT AND SYSTEMS

1. **Scope.** This chapter provides inspection and testing procedures for air handling equipment and systems that use chilled water as cooling medium. Included are central station field erected systems, central station factory packaged systems, and room terminal units (fan coil units and unit ventilators). Unitary air handling units that use refrigerant as cooling media are not included in this chapter. They may be found in chapter 8, Unitary Air Conditioning Equipment. Certain temperature controls are included in Chapter 6, Building Automation Systems.

## 2. Reference Standards.

a. ARI Standard 410 - Standard for Forced-Circulation Air-Cooling and Air-Heating Coils.

b. ARI Standard 430 - Standard for Central-Station Air-Handling Units.

c. ARI Standard 440 - Standard for Room Fan-Coil Air-Conditioners.

d. ARI Standard 610 - Standard for Central System Humidifiers.

e. ARI Standard 630 - Standard for Selection, Installation, and Servicing of Humidifiers.

f. ARI Standard 670 - Standard for Fans and Blowers.

g. ARI Standard 850 - Standard for Commercial and Industrial Air Filter Equipment.

h. ASHRAE Standard 33 - Methods of Testing Forced Circulation Air Cooling and Air Heating Coils.

i. ASHRAE Standard 41.6 - Standard Method for Measurement of Moist Air Properties.

j. ASHRAE Standard 51 - Laboratory Methods of Testing Fans for RAting.

k. ASHRAE Standard 52 - Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter.

l. ASHRAE Standard 62 - Ventilation for Acceptable Indoor Air Quality.

m. ASHRAE Standard 71 - Method of Testing for Rating Unit Ventilators.

n. ASHRAE Standard 90.1 - Energy Efficient Design of New Non-Residential Buildings and New High-Rise Residential Buildings.

o. ASHRAE Standard 111-1988 - Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air Conditioning and Refrigeration Systems.

p. Associated Air Balance Council - National Standards for Total System Balance.

q. National Environmental Balancing Bureau - Procedural Standards for Testing-Balancing-adjusting of Environmental Systems.

r. Applicable codes of the National Fire Protection Association.

s. Applicable codes of Underwriters Laboratories, Inc.

## 3. Air Handling Equipment and System Inspection.

3.1 The air handling equipment and systems shall be inspected for construction and installation to meet safety and functional requirements.

3.2 See EXHIBIT 5-A for inspection procedures. See Appendix for inspection check lists.

## 4. Air Handling Equipment and System Testing.

4.1 The air handling equipment and systems shall be tested in the field to verify capacity and performance requirements of the contract specifications.

4.2 Two basic type of tests shall be included:

4.2.1 The capacity and other performance compliance of the air handling system and components.

4.2.2 The functional compliance of the automatic control system.

4.3 If building load at time of testing does not correspond to system capacity requirements, introduction of false loads to the air handling unit or its components may be necessary. However, tests shall not cause excessively uncomfortable conditions in the building. Providing false load is the responsibility of the project contractor.

4.4 See EXHIBIT 5-B for test procedures. See Appendix for test work sheets.

## EXHIBIT 5-A INSPECTION PROCEDURES FOR AIR HANDLING SYSTEMS

### 1. Scope.

The inspection procedures described in this EXHIBIT apply to central station packaged and field erected air handling units, unit ventilators, room fan coil units, and their associated automatic temperature controls. See Chapter 6 for automatic temperature controls of systems having building automation systems.

### 2. Industry standards.

a. ARI Standard 630 (Standard for Selection, Installation, and Servicing of Humidifiers) describes humidifier selection procedure, installation practices, and service practices of humidifiers used in central stations and self-contained applications.

b. ASHRAE Standard 62 (Ventilation for Acceptable Indoor Air Quality) is a design standard which gives ambient air quality guidelines and outdoor air requirements for most space ventilation applications. It also give general requirements for ventilation systems and equipment.

### 3. Air handling system general inspection.

3.1 Review equipment manufacturer's instructions on start-up and operation procedures.

3.2 Give complete inspection of fan, motor, air filters, cooling coils, heating coils, dampers, fan and coil bases, vibration isolation units, and their associated equipment, including associated electrical equipment, piping, ductwork, etc. Be sure that no apparent damage or rusting occurred.

3.3 Check equipment name plates (air handling unit, fan, motor, air filter, coils, etc.) to verify equipment model and serial number. They must have the same model numbers as approved submittals.

3.4 Check for headrooms and access spaces around unit for operation and maintenance. Manufacturer's recommended spaces must be provided unless the contract documents specify otherwise. Pay special attention to coil and filter replacement and cleaning spaces and access spaces.

3.5 Inspect equipment room for possible fire hazards. The room should be kept free of combustible material and construction debris.

3.6 Check compliance of equipment room ventilation requirement with project drawings and specifications. If automatic dampers are specified and installed, test damper operation.

3.7 Verify service piping, pipe fittings and accessory equipment for the air handling equipment against project drawings and equipment manufacturer's recommendations for completeness and proper installation. Fittings and accessories include but not limit to valves, strainers, thermometer wells, piping supports, steam traps, etc.

3.8 Check water flow direction marks of check valves and flow switches.

3.9 Check piping at equipment connections. Pipes should be supported from building structure without undue stress on coils.

3.10 All moving parts (motors, belts, etc.) should have protective shields for personnel safety in accordance with job specifications.

3.11 Check alignment of motor driven equipment. Using some simple tools such as straight edges, square edges, plumb lines, and strings yield good results. If these instruments indicate the possibility of misalignment, checking with more sophisticated instruments should be required of the contractor. Also observe shaft and coupling for misalignment while equipment is running.

3.12 Observe belt tightness of fans. Use belt tension gage if needed. Belt tension should be as recommended by belt manufacturer. Remove equipment access panels as necessary.

3.13 Make sure required lubrication is complete (fan, motor, etc.). Use a grease gun if necessary.

3.14 Check for completeness of required instrumentation, including thermometers, gages, temperature and flow measuring and control devices. Required straight pipe runs and arrangements for temperature and flow measuring devices must be met.

3.15 Verify installed wiring against project drawings and manufacturer's submittals.

3.16 Check electric equipment and controls for proper grounding.

3.17 Check safety control wiring connections. All safety control switches ( switches respond to temperature, pressure, smoke, etc. to break the safety control circuit) should be connected in the ungrounded conductor.

3.18 Check all electrical connections for tightness with screwdriver, wrench, etc. as necessary.

3.19 For motor starter equipped with overcurrent heaters, check heater sizes against starter manufacturer's recommendations. The recommendations are usually contained in operator's manual or posted in starter cabinet.

3.20 Test-run motors (fan, pump, etc.) to check correct direction of rotation.

3.21 Check surface paint for damages and omissions. Equipment nameplates must not be painted over. Required equipment labels must be present and legible.

3.22 Note any unusual noise and vibration.

3.23 Note any water, oil, or steam leaks.

3.24 Inspect duct connections at air handling unit for excessive air leakage.

## 4. Fan.

4.1 Inspect fan housing access door and pressure latches for tightness. Open and close doors to detect interference of door with thermal insulation and other equipment.

4.2 Check assembly bolts of field assembled fans for any loose bolt.

4.3 Inspect bearing for proper oil or grease application. Grease lines for bearings should extend to outside of duct connections with grease fittings if specified. Oiling shall not require dismantling of fans, ducts, or other equipment if specified.

4.4 Inspect belt guard for access to oiling, speed counting device, and other maintenance requirements.

4.5 Observe fan steadiness during operation and excessive vibration transmission to building supporting structure.

4.6 For outlet damper or inlet vane controls inspect control linkage manually or by manipulating controller for the full range of the stroke. When a single operator controls inlet vanes of double inlet fans, inlet vanes on both inlet openings must move in unison. Inspect inlet vane rotation direction with respect to that of the fan wheel.

4.7 Fans exposed to weather should have protective weather hoods over motors and drives if specified.

4.8 For fans without duct connections, unless they are housed in plenums, they must be provided with protective devices for personnel safety such as wire mesh or expanded metal screens at inlets and outlets if specified.

4.9 For power roof ventilators check curb water-tightness.

4.10 For fans not enclosed in air handling unit casings, make sure flexible duct connections are installed between fans and ducts if specified. Check specifications for material and construction of flexible connections.

## 5. Heating and cooling coils.

5.1 Inspect heat transfer fins for damages.

5.2 Verify project specified or manufacturer's recommended slope of heat transfer tubes for drain requirements.

5.3 Inspect baffles between coils and casing to assure that air is not bypassing coils.

5.4 Inspect cooling coil drain pans. Coils must have individual pans with drain pipes for multi-coil assembly to avoid flooding of lower coils if specified. Similar arrangement is required for sprayed coil dehumidifiers.

5.5 Inspect pipe fittings, valves, and coil accessories in accordance to specifications and drawings. Included are water supply, water return, steam supply, condensate return, piping to sprayed coils, air vents, and drains.

5.6 Inspect steam coils for possible coil freezing problem. Good condensate draining must be provided: adequate slope of tubes, adequate head between coils and steam traps (minimum 18 in.), and vacuum breakers at high position of coils. Adequate sizing of steam traps should be checked if the requirements are not given in the contract specifications. Check for counter flow, air vents, drains, water trap on cooling coil, piping and water coil.

5.7 Steam main drips must be provided before coil connections if specified.

5.8 Check steam traps and condensate piping of steam coil temperature. They must not be unduly hot.

5.9 Inspect primary element installation for flow measurement devices. The specified distance of pipe lengths and accessories (such as water straightening devices) must be viewed as minimum requirements.

## 6. Air filters.

6.1 Inspect filters for air leakage between filters and holding frames and between filter assembly and unit casing. Inspect positive sealing devices for air leakage, if specified.

6.2 For automatic renewable type air filters, inspect medium advancing and override operation (pressure control, timer setting, media switch, etc. See specifications for project requirements).

6.3 Inspect filter gage sensing tips for correct static pressure sensing.

6.4 For inclined manometer type filter gages check for correct installation levels.

6.5 Filter holding frames must be anchored securely to air handling unit casing as per design drawing/specifications.

6.6 Make sure adequate access spaces are provided for filter media replacement as per design drawings/specifications.

6.7 Filter media must be new at the time of commissioning inspection.

6.8 Check the number of spare filters provided by the contractor against contract specification requirements.

## 7. Dampers.

7.1 Verify blade arrangement, bearing material and edge sealing material.

7.2 Inspect full range of damper movement by manipulating actuator. Verify damper closing position.

7.3 Felt strips should be provided for backdraft dampers if specified. Dampers shall not rattle during operation.

7.4 all dampers in ducts must have access doors if specified. Doors must be air tight.

## 8. Air louvers.

8.1 Verify material, arrangement, and dimensions.

8.2 Verify material and mesh size of bird screens.

## 9. Casings.

9.1 Inspect casing for rigidity (reinforcement and adequate bracing).

9.2 Inspect casing for integrity.

9.3 Verify access door sizes, gasket tightness, and latch arrangement.

9.4 Make sure flexible connections are installed between air handling equipment and duct system. Check specifications for material and construction of flexible connections.

9.5 For outdoor installation with factory supplied enclosures, inspect gaskets or caulking at joints for weather protection. Also inspect curb flashing for water-tightness.

## 10. Thermal insulation.

10.1 Check thermal insulation for damages and omissions.

10.2 Material, thickness, and finish of thermal insulation and vapor barrier must be as specified.

10.3 Check vapor barrier downstream of cooling coil for integrity.

## 11. Controls.

11.1 Review installed control systems with contract documents and submittals to assure that the installations are as required.

11.2 The contractor must demonstrate correct calibration of all instruments. These include temperature (water, air), pressure (steam), and other instruments as the contract specified..

11.3 Observe general operation of control system. Look for incorrect ranges and settings.

11.4 All controls containing mercury switches should be checked for proper leveling.

11.5 Examine valve operation for tight closing. Valve motors and linkages should be installed securely. Linkages should move through the entire stroke without binding or interfering with other objects.

11.6 Examine damper operation for position (closing tight?). Damper motors and linkages should be installed securely. Linkages should move through their entire stroke without binding or interfering with other objects.

11.7 If pneumatic controls are used for system controls, check the following:

11.7.1 Check control air tubing connections for tightness.

11.7.2 Check air filters (both intake air and air line)of air compressors for cleanliness.

11.7.3 Check air compressor motor alignment.

11.7.4 Check air compressor belt tightness.

11.7.5 Make sure protective shields are provided for belts and pulleys.

11.7.6 Check compressor oil level and oil filter cleanliness.

11.7.7 Test open air tank drain for possible water accumulation.

11.7.8 Check condensers of control air refrigeration units for cleanliness.

11.7.9 Check for correct air pressure at air tanks and after pressure reducing valves.

11.7.10 Check control diagrams, complete and framed with proper item identification, understandable sequence description, etc.

11.7.11 Check inside control panels: everything labeled correctly, installed neatly, settings marked, tubing numbered, appropriate last-minute notes attached to panels, all features as specified.

11.7.12 Check for air pressure gauges installed throughout system as specified, and reading correctly, both statically and during system operation.

11.7.13 Check controls functioning accurately without hunting.

11.8 For electrical and electronic control systems check for loose wire connections, broken wires, and rust terminals.

11.9 Check correct voltage of power supply.

11.10 Inspect electronic systems for ground shield cable and possible interference of magnetic field with signals.

11.11 Check safety features of air handling controls such as coil freeze protection and alarm bells.

11.12 Verify interlocking of equipment.

11.13 Note any malfunction device.

11.14 Verify entire control installation in accordance with approved submittals and operation manuals. See EXHIBIT 5-B for testing of control functions.

## 12. Fan coil units and unit ventilators.

12.1 Check type of units (wall hung, free standing, suspended, concealed) to be the type specified. All accessories should be complete.

12.2 Check motor type, speed, and construction to be same as specified. Plug in electric wires must be furnished. If oiling is required for motor bearings, extended oiling tubes should be provided.

12.3 Check fan construction and material.

12.4 Check cabinet, inlet and outlet grilles to be as specified. Check for dent or paint damages.

12.5 Check access doors for valves and controls.

12.6 Material and construction of drip pans should be as specified.

12.7 Check air filter type for specification compliance. Both outside air and recirculated air must go through air filters.

12.8 Check fan, damper, and valve controls for specification compliance. See EXHIBIT 5-B for functional test of controls.

12.9 Coil types and valve assembly shall be as specified. Check for heat transfer fin damages.

12.10 Check acoustic and thermal insulation for completeness, material, thickness, and face treatment.

12.11 Dampers should have continuous seals as specified.

12.12 If wall boxes are used for outside air, check box material and construction. Bird screen shall be provided as specified.

## EXHIBIT 5-B TEST PROCEDURES FOR AIR HANDLING SYSTEMS

1. **Scope.** The test procedures described in this EXHIBIT apply to central station packaged and field erected air handling units, room fan coil units, room air terminal units, and their associated automatic temperature controls. Also see Chapter 6 for automatic temperature controls of systems having building automation systems.

### 2. Industry standards.

a. ARI Standard 410 (Standard for Forced-Circulation Air-Cooling and Air-Heating Coils) describes the method of testing and rating of forced air cooling and heating coils and the method of establishing coil performance by extension of test data to operating conditions other than test. It lists a range of standard rating conditions for important operational parameters such as air face velocity, fluid velocity in tubes, temperature of air and fluid. Fluid used in coils tubes are refrigerant, cold and hot water, steam, and ethylene glycol solution. This standard is used in conjunction with ASHRAE Standard 33 (Methods of Testing for Rating Forced Circulation Air Cooling and Air Heating Coils.

b. ARI Standard 430 (Standard for Central-Station Air-Handling Units) describes the definition, classification, standard components, and testing and rating requirements of central-station air-handling units. It is intended to be used in conjunction with ASHRAE Standard 51 (Laboratory Methods of Testing Fans for Rating). Test results of one unit are extended to other units by the application of fan laws.

c. ARI Standard 440 (Standard for Room Fan-Coil Air-Conditioners) describes the definition, classification, standard components, and testing and rating requirements of room fan coil units. It is intended to be used in conjunction with ASHRAE Standard 79 (Methods of Testing for Rating Room Fan Coil Air-Conditioners). The standard testing and rating conditions are 80 F dry bulb and 67 F wet bulb entering air, 45 F entering water, 55 or 60 F leaving water temperature, negligible air friction through the coil, highest fan speed setting and nameplate electrical characteristics at the unit.

d. ARI Standard 610 (Standard for Central System Humidifiers) describes the testing and rating requirements of central station humidifiers installed in ducts of air heating type heaters. It states the standard testing and rating conditions of air velocity, air temperature and pressure, water temperature and pressure of various applications (humidifier location in relation to the central system). The humidification rate is measured by the net water added to the air stream at the entering air conditions.

e. ARI Standard 670 (Standard for Fans and Blowers) describes testing and rating requirements for fans and blowers. This standard is used in conjunction with ASHRAE Standard 51 (Laboratory Methods of Testing Fans for Rating Purposes). Test data may be extended by use of fan laws to other fans with certain restrictions.

f. ARI Standard 850 (Standard for Commercial and Industrial Air Filter Equipment) describes classification, testing and rating requirements, performance and safety requirements for factory-made air filter devices and air filter media. This Standard is used in conjunction with ASHRAE Standard 52 (Methods of Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter). It states standard rating conditions and values of standard ratings to be published. It also requires a breaching test to ascertain that no evidence of tearing, dislocation, or other damage to the air filter device.

g. ASHRAE Standard 33 (Methods of Testing Forced Circulation Air Cooling and Air Heating Coils) prescribes laboratory testing methods for air cooling and air heating coils. It describes test methods and procedures, testing instruments and apparatus, test data to be recorded, calculations to be made from test data, and specified standard thermodynamic properties. It is not intended for field testing.

h. ASHRAE Standard 41.6 (Standard Method for Measurement of Moist Air Properties) gives recommended practices and procedures for measurement and calculations of moist air properties. It describes moisture measuring instruments, the ranges of conditions these instruments are practical, their accuracies, and the techniques of use to achieve desired accuracies. The instruments included are psychrometer, dew point hygrometer, heated electrical salt-phase transition hygrometer, Dunmore type sensor, and electrolytic hygrometer. Calibration and reference standards are also discussed.

i. ASHRAE Standard 51 (Laboratory Methods of Testing Fans for Rating) prescribes methods for laboratory testing of rating fan performance in terms of flow rate, pressure, power, air density, speed of rotation, and efficiency. It gives basic fan-related definitions, instruments and methods of measurements, test equipment and setups, calculation equations, and some air and equipment data. It must be cautioned that when performing fan tests, field conditions of fans, ducts, and other associated equipment usually alter test results significantly from those of laboratory conditions.

j. ASHRAE Standard 52 (Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter) describes the test apparatus and procedures for testing the performance of air-cleaning devices used in air handling applications. It evaluates air-cleaning devices by determining their particulate arresting efficiencies, time for replacement or cleaning, and their resistances to air flow. Both ambient atmospheric contaminants and synthetic dust may be used in tests. This Standard should not be used for testing air-cleaning devices having efficiencies higher than

98%.

k. ASHRAE Standard 71 (Method of Testing for Rating Unit Ventilators) describes laboratory testing methods, instruments, apparatus, and test procedures for unit ventilators. It also gives calculation equations for air and other variables of unit heaters.

l. ASHRAE Standard 79 (Methods of Testing for Rating Room Fan-Coil Air Conditioners) prescribes laboratory testing and rating methods for fan coil units. It describes test instruments and measurement methods, apparatus, test procedures, and calculation equations.

m. ASHRAE Standard 90.1 (Energy Efficient Design of New Non-Residential Buildings and New High-Rise Residential Buildings) prescribes the requirements for efficient energy design of new human occupied buildings. Covered are exterior building envelopes, HVAC systems and equipment, service water heating, lighting systems, and other auxiliary equipment. Mandatory requirements are specified for compliance of energy efficient use. Alternative methods of compliance are allowed: prescriptive, system performance, and annual energy consumption.

n. Associated Air Balance Council National Standards (National Standards for Total System Balance) is an industry standard for establishing a minimum set of field and balancing standards. This Standard together with the one in paragraph o. below differ from all other standards listed here in that the purpose of these two standards are solely for field testing, adjusting, and balancing of HVAC systems. This Standard describes measurement instruments and their use, some basic system design information, and procedures for testing, adjusting, and balancing of air and water systems. Detailed equipment testing is not included.

o. National Environmental Balancing Bureau Standard (Procedural Standards for Testing-Balancing-adjusting of Environmental Systems) is a standard similar in purpose and practice to the previous standard for field testing, adjusting and balancing of HVAC systems.

## 3. General.

3.1 One of the most important measurement in air handling system testing is the measurement of air flow rates of the system. This measurement is used in most installation to verify almost all component (fan, heating coils, cooling coil, air filter, humidifier, and other components) capacities.

3.2 Field tests of air handling systems are separated into two groups in this guide. The air handling unit component tests are based on steady state operating conditions to verify the peak capacities of the components. The air handling system operational tests mainly verify the control operations of the systems.

3.3 Unless specifications require otherwise, air handling systems having air flow rates over 1.888 $m^3/s$ (4000 $ft^3/min$) should have full level tests as outlined in this guide. For air handling systems having air flow rates at or less than 1.888 $m^3/s$ (4000 $ft^3/min$), total air flow rates and cooling/heating temperature differentials (from inlet to outlet of units) should be verified and the components tests are not required.

3.4 Functional inspection and test process is based on the premise that the construction contractor has tested, adjusted, and balanced the entire air and water systems and is ready for normal operation. Certain preparatory procedures listed in this section are needed before commencing functional inspection and tests of components and systems.

3.5 All architectural openings, such as windows and doors, should be at their normally used positions (Check both architectural and mechanical drawings).

3.6 All fans (supply, return, exhaust, transfer) which may influence the air balance in the area should be operating at their normal conditions.

3.7 All system interlocks should be at their normal operational conditions.

3.8 All safety devices and provisions have been inspected and tested already.

3.9 The space temperature and humidity controls should be set at normal operating conditions.

3.10 air flow rate measurement of fans and subsystems (if air flow rates differ from that of the main fan) should be performed before other tests.

3.11 All manual damper positions as set by the construction contractor should be marked before they are attempted to be changed for tests, so that their original positions may be restored, if necessary.

3.12 It should be recognized that most installations of air systems are not at ideal conditions for flow measurements. Extraordinary caution and details should be paid to the selection of sensor locations and measurement techniques.

3.13 Fan ratings supplied by fan manufacturers and air flow rates of the design documents are generally in standard air conditions (approximately dry air at 21.1 °C (70 °F) and 101.3 kPa (29.92 in. of Hg), or 1.20 $kg/m^3$ (0.0750 $lb/ft^3$) unless noted otherwise. It is generally adequate to use volumetric flow rates for commissioning purpose. If the temperature, humidity, and barometric pressure differ substantially from those of the standard air, the volumetric flow rates from the test results must be adjusted.

3.14 Check if there are dampers installed in main ducts and have no function in balancing air between duct branches such as fire or smoke dampers), make sure the blades of these dampers parallel to the air flow.

3.15 The preferred method of measuring air flow rate is the pitot tube traverse method. It is extremely important in selecting the location in the ducts for the pitot measurement. If packaged air flow measuring stations are specified and installed, they should be used after a preliminary check of its performance. Use SE-9 or -10 for air velocity measurement and SE-12 for volume air flow rate from EXHIBIT 2B, Chapter 2.

## 4. Instrumentation.

4.1 Make sure that all instrumentation are in good working orders and are in calibration. See Chapter 2 BASIC MEASUREMENT for calibration of instruments.

4.2 Instruments required by the contract specification and/or installed by the contractor or equipment manufacturers may be used for performance tests, if they meet the accuracy and calibration requirements of this Section. The glass thermometers installed on water pipes for maintenance purposes do not usually meet the requirements for performance tests.

4.3 The required measurement, minimum accuracies, and measurement precautions of instruments are given below:

4.3.1 Temperature.

4.3.1.1 Entering and leaving water temperature of water coils, and entering and leaving hot water of hot water humidifiers. The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

4.3.1.2 Direct measurement of temperature differential of entering and leaving water for the applications of paragraph 4.3.1.1 above. For calculating coil energy amount, this measurement is preferred than deducing the difference from separate temperature measurements of entering and leaving water. The measurement error shall not exceed +/- 0.1 °C (0.2 °F).

4.3.1.3 Steam temperature of steam coils and steam humidifiers. The measurement error shall not exceed +/- 0.6 °C (1 °F). Locate sensing device after steam control valves.

4.3.1.4 Condensate temperature of steam coil. The measurement error shall not exceed +/- 0.6 °C (1 °F). Locate sensing element after traps. If coils are individually trapped, temperature sensing device should be in the combined condensate pipe.

4.3.1.4 Entering and leaving air temperature of coils and humidifiers. The measurement error shall not exceed +/- 0.28 °C (0.5 °F). Stratification is a common phenomenon in air measurement. Since both the flow rate and temperature distribution may vary across the coils or air plenums, it is important to obtain the flow rate weighted average temperature of the flow. At least one measurement at each one square foot of coil face area or plenum cross-sectional area shall be taken unless the measurement is for outside air or the measurement is taken in a thoroughly mixed air stream.

4.3.1.5 Direct measurement of temperature differential of entering and leaving air. For calculating energy amount, this measurement is preferred than deducing the difference from separate temperature measurements of entering and leaving air in applications of measuring air temperature differentials. The measurement error shall not exceed +/- 0.28 °C (0.5 °F). Precautions for measurements described in the previous paragraph must be observed.

4.3.1.6 Entering and leaving air relative humidity, wet bulb temperature, or dew point temperature for cooling coils and humidifiers. The measurement error shall not exceed +/- 0.6 °C (1 °F) wet bulb or equivalent. The humidity conditions before and after a coil may also be stratified. With certain instruments such as sling psychrometers it is difficult to make multiple measurements across the face of the coil. Locations away from coils should be selected for single humidity measurements. If digital electronic hygrometers are used, they should be calibrated against a sling psychrometer in the field.

4.3.2 Flow rate. Water or steam flow rates for coils or humidifiers. The total error of combined sensing and readout devices shall not exceed +/- 3% of specified flow rates. The minimum pipe length requirements must be observed or flow straightener installed in accordance with the recommendations of Chapter 2, BASIC MEASUREMENT.

4.3.3 Pressure.

4.3.3.1 Steam pressure. The total measurement system error shall not exceed +/- 3448 Pa (0.5 psi). Steam pressure shall be measured after steam control valve.

4.3.3.2 Pressure gages installed on pipes for the purpose of maintenance operation may be used to measure the water pressure at inlet and outlet of coils if they are calibrated and meet accuracy requirements. The measurement error shall not exceed +/- 3448 Pa (0.5 psig).

4.3.3.3 Air static pressure and total pressure measurement. The total measurement system error shall not exceed +/- 12.4 Pa (0.05 in. of water).

4.4 Instrumentation calibration test work sheet for air handling systems, WS 5B-1, is included in the appendix.

## 5. Air handling unit component tests.

5.1 Fan performance test. The total air flow rate of a system must be measured and verified to meet specifications first before all other measurements. Additionally, air distribution to individual outlets must also be measured and verified as outlined in Setions 5.1.9 and 5.1.10.

5.1.1 Project specification for fans are usually given in flow rate and static pressures pairs. The flow rates are the actually required air quantities. The pressure requirements are only estimates. After a construction project is balanced by the air balancing contractor, the system should provide the specified flow rates at the finally adjusted fan pressure. This pressure in most cases may be different from the specified rates.

5.1.2 When fans are tested and rated in the laboratories, they are tested under ideal inlet and outlet conditions as prescribed in the ASHRAE (and AMCA) standards. In overwhelming cases of actual installations, the site conditions of ducts (also called system effect factors) alter the fan performance, sometimes substantially. The fan manufacturers base their submittals on matching the performance of the laboratory (or allowed equivalent) results (fan curves or tables) with estimated air friction (the specified pressure head). Any mismatch between the laboratory performance and the actual performance is corrected by adjusting and balancing of the entire air system. Therefore, during commissioning process it is important that a) the measured fan air flow rates satisfies the specified fan air flow rates; b) all spaces receive their required air flow rates; and c) the measured fan pressure heads not necessary equal the specified fan pressure heads.

5.1.3 There is no fixed rules which can be applied universally in selection of measurement methods in determining air flow rates of fans. The persons responsible for functional performance tests must use their judgement in deciding the method or combination of methods for performing the test.

5.1.4 Using Pitot tube to traverse the main ducts of the air handling unit is the preferred method. Make sure the air flow at the location of measurement is steady (after minimum length of straight duct run or after straightening vanes). See EXHIBIT 2-C, STP-5 for measurement procedures.

5.1.5 Measuring air flow rates at coil face or air filter face with anemometer may be used for supply fan measurement, if good locations for pitot measurement can not be found. See EXHIBIT 2-C, STP-6 for measurement procedures.

5.1.6 Because of possible external and internal disturbances, air flow rate, pressure, electric current rate, power consumption, and fan speed measurements shall be repeated 3 times and the results averaged to represent the fan performance.

5.1.7 Required measurement data:

5.1.7.1 Total air flow rate, Q, in $m^3/s$ ($ft^3/min$)

5.1.7.2 Depending on ductwork arrangement of the air handling unit (lacking inlet or outlet duct), the pressure measurement are different. Consult EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS for measurement requirements of different duct systems. The majority of installations have inlet and outlet ducts (or plenums) for fans. The following pressures, all in units of Pa (in. of water), should be measured.

* Total pressure at fan inlet duct, $P_{tin}$
* Total pressure at fan outlet duct, $P_{tout}$
* Static pressure at fan inlet duct, $P_{sin}$
* Static pressure at fan outlet duct, $P_{sout}$
* Velocity pressure at fan inlet duct, $P_{vin}$
* Velocity pressure at fan outlet duct, $P_{vout}$
* Barometric pressure.

5.1.7.3 Voltage of electrical service, V

5.1.7.4 Electric current, A

5.1.7.5 Rotating speed of fan, rpm

5.1.8 It is the responsibility of the construction contractor to provide a fan to meet the construction specifications and to adjust and balance the entire air system. The entire air system must operate stably. During functional performance testing the commissioning team should make sure that the system stability is achieved by measuring the fan speed. Use a tachometer or stroboscope (see EXHIBIT 2-A COMMONLY USED FIELD TEST INSTRUMENTS) to measure the fan speed continuously for at least 3 minutes. The speed variation shall not exceed 3% of the run.

5.1.9 Test procedures for constant air volume systems.

5.1.9.1 Set the outside air damper at the minimum position and the return air and relief air dampers at their appropriate positions. Disable damper automatic controls during test. (See Section 7 for testing of outside air damper settings).

5.1.9.2 Perform the required measurements listed in 5.1.7 above.

5.1.9.3 Check air flow rates to individual spaces. Select air outlets randomly throughout the entire duct system from the same air handling unit. If 10% of the outlets checked is off for more than 10% of the specified flow rates, a second set of 10% outlets shall be checked. The entire air distribution system, including fans and all dampers, must be rebalanced and testing repeated, if (i) any 10% of the outlets checked have flow rates off +/- 15% from the specified flow rates; or (ii) the total of all measured flow rates of these outlets is off +/- 10% from the total of the design flow rates of the same outlets.

5.1.9.4 Set the outside air to 100% and other dampers (return and relief dampers) to their appropriate positions.

5.1.9.5 Measure electric current rate. The motor current rate must not be greater than the full load current shown on the motor mane plate.

5.1.9.6 Restore all damper controls.

5.1.10 Test procedures for variable air volume (VAV) systems.

5.1.10.1 It is difficult, if not impossible, to know when the system block loads occur. Fans of variable air systems can only be tested to verify their capacities and energy rates in accordance to the specified values despite that the pressure requirements are only estimated.

5.1.10.2 Set the outside air damper at 100% position and the return air and relief air dampers at their appropriate positions. Disable damper automatic controls during test.

5.1.10.3 Manipulate duct pressure sensors by applying simulated pressure changes (thus change the fan curves on a volume-pressure diagram) and manipulate the air volume controls of the first few air outlets (thus change the system curves of the volume-pressure diagram). The contract specified fan duty point (volume flow rate and pressure) may be obtained during test. Repeated adjustment and measurement may be needed.

5.1.10.4 Perform the required measurements listed in 5.1.7 above.

5.1.10.5 The electric current rate of the motor shall not be higher than the name plate full load current.

5.1.10.6 Use similar procedures test variable air volume return air fans.

5.1.10.7 Restore all damper controls.

5.1.10.8 Randomly select a minimum of 10% of VAV units which are supplied from the same air handling system. Measure the maximum and the minimum supply air flow rates of these units by manipulating their respective thermostats. If 10% of the selected units having their flow rates (maximum and minimum) differ more than 10% of the specified flow rates, a second set of 10% units should be selected and measured. The entire air system must be rebalance and testing repeated, if (i) any 10% of the units measured have flow rates off +/- 15% from the specified flow rates; or (ii) the total of all measured flow rates of the selected VAV units differs over +/- 10% from the total of the design flow rates of the same units.

5.1.10.9 During the maximum and the minimum air flow rate manipulation, verify the operation sequence of reheat coils (for units with reheat coils), recirculating fans (for units with recirculating fans), and other operational controls as required in the contract specifications.

5.1.10.10 Measure and verify the required duct static pressure at the locations of each fan static pressure sensor.

5.1.10.11 Measure static pressure of at least 25% of all branch ducts just before the last VAV unit of the branch to verify that the pressure is within + 49.8 Pa (0.2" of water) of the specified minimum pressure of the VAV units. If the static pressure is lower than the minimum pressure required or more than the total of minimum pressure plus 49.8 Pa (0.2" of water) the fan static pressure controller setting must be adjusted and duct pressure retested. The selection the these 25% branches should be estimated and judged by the Team that these branches may encounter extreme (high or low) pressure during building load changes.

5.1.11 Test work sheet for fan is included in sheets for air handling system component tests, 5B-2, in the appendix.

5.2 Heating and cooling coils.

5.2.1 Coil measurements should be performed after fan measurements.

5.2.2 Depending on the weather at the time of testing, false cooling or heating loads may be needed to achieve the contract specified entering air conditions. If false loads are not available at the time of commissioning, the heating and cooling coil tests must be postponed till the specified conditions may be maintained.

5.2.3 Test procedures for water and steam coils.

5.2.3.1 Measure air flow rate through coils. See paragraphs 5.1.4, 5.1.5, and 5.1.6 above for measurement details. For systems having the same air flow rates through fans and coils, the measured air flow rates through fans shall be used for coils.

5.2.3.2 Measure water flow rate of water coils. Adjust balancing devices, if necessary, to within 3% of the contract specified flow rate. This water flow rate shall be maintained during the test.

5.2.3.3 Measure entering water temperature of water coil. Adjust, if necessary, to within 0.6 °C (1 °F) from the contract specified temperature. This temperature shall be maintained within 0.3 °C (0.5 °F) during the test.

5.2.3.4 Measure steam pressure and temperature for steam coils. Check pressure and temperature against steam table to make sure that steam is at least saturated and that the steam pressure after control valve is at the specified pressure of the coil. If the indicated pressure is more than +/- 6.895 kPa (1 psi) from that specified, the steam line pressure controlling device must be adjusted. If the steam is less than saturated, it must be brought to saturation conditions before test is continued. The pressure and temperature of the steam shall be maintained during the test.

5.2.3.5 Measure steam flow rate to the coils. Adjust manual or automatic valve, if necessary, to within 3% of the contract specified flow rate. This flow rate shall be maintained during the test.

5.2.3.6 In order to maintain the water entering temperature and flow rate, or the steam conditions and flow rate, the automatic controls of the tested coils should be disabled during the test after first verifying the status (N.O. or N.C.) of the valve/damper actuator.

5.2.3.7 Measure entering air dry bulb temperature. Temperature control of the air upstream of the coil may need to be adjusted or false load varied to maintain this temperature within 0.6 °C (1 °F) of the contract specified entering air dry bulb temperature. For cooling coil, the adjustment of upstream air temperature may need be performed in conjunction with adjustment of upstream air humidity (see the following) paragraph.

5.2.3.8 For cooling coil test, measure the entering air humidity (relative humidity, wet bulb temperature, or dew point temperature). Usually humidity needs to be added in the air by manipulating humidifier or false humidity load source. The humidity must be maintained within 3% RH or equivalent of the contract specified value.

5.2.3.9 Run the air handling unit for at least 10 minutes to prove that the system is under steady state conditions. Steady state condition is achieved when the average of three consecutive measurements of coil leaving air temperature, at 5 minute intervals, do not differ by more than 1.1 °C (2 °F).

5.2.3.10 Measure barometric pressure.

5.2.3.11 Measure coil leaving water temperature.

5.2.3.12 Measure Water pressure at coil inlet and outlet of water coils.

5.2.3.13 Measure air static pressure at upstream and downstream air of coils.

5.2.3.14 Take three sets of air data at 5 minute intervals:

* Entering air dry bulb temperature.

* Leaving air dry bulb temperature.

* Entering air relative humidity, wet bulb temperature, or dew point (for cooling coils only).

* Leaving air relative humidity, wet bulb temperature, or dew point temperature (for cooling coil only).

5.2.4 Separate test work sheets for heating coil and cooling coil are included in test work sheets for air handling system component tests, WS 5B-2, in the appendix.

5.3 Humidifiers.

5.3.1 Numerous types of humidifiers are being used in different applications. The test procedures described in this section applies to humidifiers which discharge steam directly into the air stream.

5.3.2 Humidifiers should be tested after fan and coil tests to assure that the capacities of the fan and coil which affect the performance of the humidifier meet the contract specification.

5.3.3 The test may be performed at any entering air temperature. The commissioning team should be sure that the air leaving the humidifier section do not reach 80% RH.

5.3.4 Test procedures.

5.3.4.1 Measure air flow rate through the humidifier section of the unit. See paragraphs 5.1.4, 5.1.5, and 5.1.6 above for measurement details.

5.3.4.2 Measure steam pressure and temperature at steam supply pipe. Check steam tables to make sure that steam is at least saturated and that the steam pressure is at the specified pressure. If the indicated pressure is more than +/- 6.895 kPa (1 psi) from that specified, the steam line pressure controlling device must be adjusted. Correct the degree of steam saturation, if the steam is less than saturated, before proceeding testing. The steam pressure shall be maintained during the test.

5.3.4.3 Adjust humidifier controls to full capacities. Maintain full capacity during the test.

5.3.4.4 Let system run for at least 10 minutes.

5.3.4.5 Take three sets of air data at 5 minute intervals:

* Entering air dry bulb temperature.

* Leaving air dry bulb temperature.

* Entering air relative humidity, wet bulb temperature, or dew point temperature.

* Leaving air, relative humidity, wet bulb temperature, or dew point.

5.3.4.6 Observe the humidifier operation. There should not be "spitting" of water.

5.3.5 Test work sheet for humidifier is included in test work sheets for air handling system component tests, WS 5B-2, in the appendix.

5.4 Air filter.

5.4.1 It is not feasible to test air filter efficiencies and dust holding capacities in the field. They must be tested in the laboratories in according with industry standards. See construction specifications.

5.4.2 For operational testing of air filters see EXHIBIT 5-A, INSPECTION PROCEDURES FOR AIR HANDLING SYSTEMS.

## 6. Calculation and evaluation of performance of air handling components.

6.1 Fans.

6.1.1 The measured total air flow rate of the fan must be within 5% of the specified fan air flow rate. The motor current rate must not be greater than the full load current shown on the motor mane plate.

6.1.2 Calculate the fan total pressure or fan static pressure from pressure measurements. For the reasons stated in paragraphs 5.1 above, this pressure should be used for reference only, if the other data show that the fan performance is satisfied.

6.1.3 Air flow rates in construction documents and manufacturer's literature are usually given in standard air conditions. Designers usually do not adjust air properties for HVAC applications below 610 m (2000 ft) altitude. Therefore no correction to measured data is required for ordinary heating and cooling applications below this altitude. For applications above 2000 ft, the commissioning team should be careful in determining the basis of air flow rates as required in the construction documents. The Team should make sure that the measured data and the required rating are on the same basis. For adjusting of air properties at higher altitudes, see EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS.

6.2 Heating and cooling coils.

6.2.1 For heating coils the entering and the leaving air humidity are not required to be measured in this guide. The errors of the enthalpy of air caused by this simplification are not significant if a 50% RH coil entering air humidity is assumed. This assumption is justified for the majority of HVAC applications.

6.2.2 The construction documents should state the basis of coil capacity. If the basis of volumetric airflow rates are not stated, assume they are for standard air.

6.2.3 Calculation procedure. The three sets of measured data shall be separately calculated to get the coil capacity. Each set of data is calculated as follows.

6.2.3.1 Calculate the saturated water pressure of the entering air, $(P_{sw})_{ent}$, kPa (in. of Hg), knowing the entering air dry bulb temperature, using SE-1.

6.2.3.2 Calculate the entering air vapor pressure, $(P_w)_{ent}$, kPa (in. of Hg), knowing the measured humidity of entering air for cooling coil or the assumed humidity (50% RH) of the heating coil, using SE-2.

6.2.3.3 Calculate humidity ratio of entering air, $(W)_{ent}$, kg (in) of vapor/kg (lb) of dry air, using SE-3.

6.2.3.4 Calculate enthalpy of entering air, $(H)_{ent}$, kJ/kg (Btu/lb) of air, using SE-4.

6.2.3.5 Calculate enthalpy of leaving air, $(H)_{lvg}$, kJ/kg (Btu/lb) of air), using SE-4. For cooling coil both the dry bulb temperature and humidity are as measured. For heating coil assume the leaving air has the same humidity ratio as the entering air (calculated in 6.2.3.4 above).

6.2.3.6 Calculate specific volume of air, v, $m^3/kg$ ($ft^3/lb$) of air), using SE-5. The air temperature at the flow measurement location must be used in this calculation.

6.2.3.7 Calculate mass flow rate of air, M kg/s (lb/min), using SE-14. The measured volume air flow rate, Q, $m^3/s$ ($ft^3/min$), is needed in the calculation.

6.2.3.8 Calculate heating or cooling capacity of coil.

Capacity, W (Btu/h)

$$= M\ [(H)_{lvg} - (H)_{ent} \qquad \text{(For SI)}$$

$$= 60\ M\ [(H)_{lvg} - (H)_{ent}] \qquad \text{(For Customary)}$$

6.2.3.9 Calculate net water pressure drop of water coils.

6.2.3.10 Calculate net air friction across coils for coils.

6.2.4 The average of three calculated coil capacities shall not be less than 95% of the contract specified capacity if no tolerance is specified. Check project specifications for specified commissioning tolerances.

6.2.5 The test water coil water pressure drop shall not be greater than 110% of the contract specified pressure drop if no tolerance is specified.

6.2.6 The test air friction of coil shall not be greater than 110% of the contract specified air friction if no tolerance is specified.

6.3 Humidifiers.

6.3.1 Calculate the average entering air and the average leaving air dry bulb temperature from measured data.

6.3.2 Calculate the average relative humidity, wet bulb temperature, or dew point temperature of the entering and the leaving air from measured data.

6.3.3 Calculate the saturated water pressure of the entering air, $(P_{sw})_{ent}$, Pa (in. of Hg), knowing the entering air dry bulb temperature, using SE-1.

6.3.4 Calculate the entering air vapor pressure, $(P_w)_{ent}$, Pa (in. of Hg), knowing the measured humidity, using SE-2.

6.3.5 Calculate humidity ratio of entering air, $(W)_{ent}$, kg (lb) of vapor/kg (lb of dry air, using SE-3.

6.3.6 Calculate the saturated water pressure of the leaving air, $(P_{sw})_{lvg}$, Pa (in. of Hg), knowing the leaving air dry bulb temperature, using SE-1.

6.3.7 Calculate the leaving air vapor pressure, $(P_w)_{lvg}$, Pa (in. of Hg), knowing the measured humidity, using SE-2.

6.3.8 Calculate humidity ratio of leaving air, $(W)_{lvg}$, kg (lb) of vapor/kg (lb) of dry air, using SE-3.

6.3.9 Calculate specific volume of air, v $m^3$/kg ($ft^3$/lb), using SE-5. The air temperature at the flow measurement location must be used in this calculation.

6.3.10 Calculate mass flow rate of air, M, kg/s (lb/min), using SE-14. The measured volume air flow rate, Q, $m^3$ ($ft^3$/min), is needed in the calculation.

6.3.11 Calculate humidifier capacity.

Capacity, kg/s (lb/h)

$$= M\ [(W)_{lvg} - (W)_{ent}] \qquad \text{(For SI)}$$

$$= 60\ M\ [(W)_{lvg} - (W)_{ent}] \qquad \text{(For Customary)}$$

6.3.12 The above calculated humidifier capacity shall not be less than 95% of the contract specified capacity if no tolerance is specified.

6.3.13 The humidifier shall not "spitting".

## 7. Air handling system operational tests.

7.1 System operations of air handling systems are very much individualized depending on the system design and control arrangements. The following operational test procedures are given for commonly used systems and control schemes. The commissioning team should review construction documents and contractor's submittals carefully before testing. The Team should emphasize on functional compliance to contract documents. Although some test work sheets are attached in the appendix for field use, the commissioning team may fine it necessary to develop its own test work sheets following similar format given.

7.2 During testing of control operations pay special attention to sequencing of controlled devices (coil valves, damper motors, etc.). Make sure they are not overlapped to cause wasting of energy over the entire operating range.

7.3 Observe the operation of controlled devices for hunting. Controller set points must be varied to set the controlled devices in operation for observation of unstable operation.

7.4 Checking of minimum outside air damper setting.

7.4.1 In most installations, locations for good measurement of outside air by pitot tube or anemometer are often difficult to find. The return air duct openings and the outside air louvers and dampers usually generate turbulence in the outside air stream. If direct measurement of outside air quantity is not feasible, air mixing method may be used.

7.4.2 Air mixing measurement procedure.

7.4.2.1 Turn off all heating coil, cooling coil, and humidifier of the unit (see paragraph 7.4.2.8 below for exceptions) to minimize the influence of air temperature change. If the outdoor temperature is below freezing, be careful to protect coils from freezing.

7.4.2.2 Disengage economy control.

7.4.2.3 Make sure the maximum outside air damper is fully closed for systems having separate minimum and maximum outside air dampers. For systems having only one set of outside air dampers the outside air damper should be at its minimum outside air position.

7.4.2.4 Measure the return air temperature and humidity in the return air duct. If return fan is installed in the system, this measurement is done between the return air fan and the air handling unit. Measurement location should not be too distant from the unit.

7.4.2.5 Measure the outside air temperature and humidity at a location not too distant from the outside air intake.

7.4.2.6 Measure the mixed air temperature and humidity. Air stratification is usually a problem in making these measurements. If the coils and humidifier are valved off, this temperature may be taken at any location before the supply air fan, such as after the air filters, the heating coils or the cooling coils. The farthest point from the air mixing chamber is the preferred location. If the coils and humidifier are not turned off, the only location for this measurement is at the main air filter bank. At either the air filter or the coil bank, the entire face of the filters or coils must be divided into one square foot grids for temperature readings and two equal side-by-side areas for humidity readings. The mixing temperature and humidity are the algebraic averages of their respective readings.

7.4.2.7 Calculate the outside air quantity by the formula:

$$\text{outside air } Q_o = Q_s \frac{H_m - H_r}{H_o - H_r}$$

where $Q_o$ = minimum outside air quantity, $m^3/s$ ($ft^3/min$)
$Q_s$ = supply air quantity measured during component tests, $m^3/s$ ($ft^3/min$)
$H_m$ = average mixed air enthalpy, kJ/kg (Btu/lb) of air
$H_r$ = return air enthalpy, kJ/kg (Btu/lb) of air
$H_o$ = outside air enthalpy, kJ/kg (Btu/lb) of air

See paragraph 6.3 for calculation procedures of enthalpy.

7.4.2.8 Since the differences of two enthalpies are used in the calculations, it is extremely important that the temperature and humidity measurements be performed accurately. The accuracy of this test may be increased by increasing the difference of enthalpies between outside air and return air. Operating appropriate coil of the air handling unit may achieve this goal. For example, increasing return air temperature by operating reheat coils or space heating during cool weather will increase accuracy. However, this approach must be weighed against measurement difficulties stated in paragraph 7.4.2.1 above. If the temperature difference between the outside air and return air is less than 8.3 °C (15 °F) the test should be postponed. In performing temperature and humidity measurements same instruments must be used for all three measurements.

7.4.3 Test work sheet for checking outside air damper setting is included in test work sheets for air handling system control operation tests, WS 5B-3, in the appendix.

7.5 Economy cycle controls.

7.5.1 There are different versions of economy cycles. The commissioning team should review the contract specifications and be familiar with the ones being applied in the subject units. The following procedures are used as examples of some economy cycles. They may need to be modified to suit a particular economy cycle.

7.5.2 Test procedures for dry bulb economy cycle.

7.5.2.1 Determine from the project documents and the automatic temperature control submittals the following temperature: the change-over temperature above which the system admits minimum outside air only; the upper and the lower temperatures enclosing the region where the system admits 100% outside air; and the temperature below which the preheater valve opens.

7.5.2.2 On a psychometric chart plot the three dry-bulb lines of paragraph 7.5.2.1, dividing the chart into 4 regions: minimum outside air with cooling valve on, 100% outside air with cooling valve on, outside air and return air dampers modulating with cooling valve off, and minimum outside air only with preheater valve on. Some design of dry-bulb economy cycle use only two dry-bulb lines and 3 regions: minimum outside air with cooling valve on, outside and return air dampers modulating with cooling valve off, and minimum outside air only with preheater valve on.

7.5.2.3 If an outdoor air sensor is installed as the change-over temperature sensor, use STP-1 to simulate the outdoor temperature. The simulator will be manipulated to vary the air damper and coil valve operation.

7.5.2.4 Use a temperature simulator to simulate the mixed air temperature sensor (STP-1). This temperature simulator will also be manipulated to vary the air damper and coil valve operation.

7.5.2.5 Observe damper and valve operations while manipulate the two temperature simulators. They should agree with the psychrometric chart regions. Actual operation of physical movement and positioning of dampers must be observed. These movements may be compared to pneumatic or electrical signal to the actuators, but the output readings (gage or meter) should be used only after verifying the meter or gage readings accurately indicate actual valve or damper position.

7.5.2.6 Simulate outdoor temperature at different regions of the psychrometric chart, especially at both sides of the region dividing lines.

7.5.2.7 The change-over temperature test shall be repeated for "specified change-over temperature plus 2.8 °C (5 °F)" and "specified change-over temperature minus 2.8 °C (5 °F)".

7.5.2.8 Record the test results, remove the temperature simulators, and restore the temperature sensors.

7.5.3 Test procedure for enthalpy economy cycle.

7.5.3.1 Replace the two temperature and two humidity sensors of the economy control with temperature and humidity simulators (STP-1 and STP-2).

7.5.3.2 Measure the supply air temperature at the supply air fan discharge.

7.5.3.3 Divide a psychometric chart into 4 regions by plotting: a) a constant enthalpy line from the saturation line to the space condition and from this state to the zero-humidity ratio line along a constant dry-bulb temperature line; b) a constant dry-bulb line through the measured supply air temperature; and c) a dry-bulb temperature line below which the system should admit only the minimum outside air (determined from the project documents). The regions having higher enthalpy and dry-bulb air temperature than the space air state should admit minimum outside air only. The region enclosed by this region and the cooling coil discharge dry-bulb line should admit 100% outside air. The region between the cooling coil discharge air dry-bulb line and the minimum outside air line should vary outside air amount by sensing the mixed air temperature. And the region below the minimum outside air line should admit only the minimum outside air.

7.5.3.4 Manipulate the outside air temperature and humidity simulators in each of these four regions and observe the outside air dampers, preheater valves, and cooling coil valves. Special attention should be paid to the immediate areas at both sides of the region dividing lines.

7.5.3.5 Record the test results, disconnect the temperature and humidity simulators, and restore the sensor connections.

7.5.4 Because of the diversity of economy cycle controls, work sheets are not provided. Make test work sheets to suit the control specifications of the unit.

7.6 Warm-up/cool-down cycle.

7.6.1 For systems having automatic shutdown during unoccupied hours, they may have warm-up and cool down cycles together with unoccupied temperature setback or setup. These systems usually require the outside air dampers closed during the starting up time (from the time of turning on the systems to the time of scheduled occupancy time).

7.6.2 At the time of this test the air handling systems are most likely to be in occupied mode. It is necessary to test the sequence of controls of shutting-down, outside air damper operation, unoccupied temperature maintenance, and starting-up.

7.6.3 The following is the test procedure for one possible control sequence.

7.6.3.1 Install temperature simulators in place of occupied and unoccupied temperature controllers (STP-1) and manipulate unoccupied temperature simulator not to interfere with the occupied time control.

7.6.3.2 Advance timer just past system-off time.

7.6.3.3 Observe system operation and outside air damper position. Supply fan should be off. Heating and cooling coil valves should be in their status according to specifications. Outside air dampers should be closed.

7.6.3.4 Manipulate unoccupied temperature simulator to activate the system. The simulated temperature activating the system should be within 1.1 °C (2 °F) of specified unoccupied temperature. The heating or cooling coil valve should be open according to specifications. The outside air damper should remain closed.

7.6.3.5 Manipulate unoccupied temperature simulator to deactivate the system.

7.6.3.6 Advance timer to just past the warm-up or cool-down time. The system should be on, if the occupied temperature controller is not satisfied. Otherwise, the system should remain off. When the system is on the outside air damper should remain closed.

7.6.3.7 Advance timer to just past the system starting time. The system should be on and the outside air damper should open.

7.6.3.8 Restor timer to its correct time.

7.6.3.9 Remove temperature simulator and restore to original temperature controls.

7.6.4 Testing of warm-up/cool-down cycle is included in test work sheets for air handling system control operation tests, WS 5B-3, in the appendix.

7.7 A single controller set at a certain controlled variable to control a component equipment (such as coil or fan).

7.7.1 Examples:

7.7.1.1 Controller having its temperature sensor located in heated air stream to control preheat coil.

7.7.1.2 Controller having its temperature sensor located in outside air to control preheat coil.

7.7.1.3 Controller having its humidity sensor in humidified air stream or conditioned space to control humidifier.

7.7.1.4 Controller having its temperature sensor in space or duct to control reheat coil.

7.7.1.5 Controller having its temperature sensor in air plenum or duct to control cooling coil.

7.7.1.6 Controller having its pressure sensor or differential pressure sensor in air duct to control variable speed fan or damper for variable volume air system.

7.7.2 These controllers may have second sensors (called overriding sensors in this test procedure) set at another level of the controlled variable to override or limit the first sensors' signals.

7.7.3 Test procedure:

7.7.3.1 Use a simulated sensor (temperature, humidity, pressure, etc.) to simulate the controller sensor (STP-1, 2, or 3).

7.7.3.2 Use a second simulated sensor to simulate the overriding sensor (STP-1, 2, or 3) if the overriding sensor is specified.

7.7.3.3 Determine from the project documents and submittals the respective set points of the sensor and overriding sensor.

7.7.3.4 Set the simulated overriding sensor in such a level that it allows the simulated sensor to control the equipment.

7.7.3.5 Manipulate the simulated sensor output and observe the action of the controlled device. The actions of the controlled device should be in agreement with the controller's differential or throttling range.

7.7.3.6 While the controlled device is operating in its operating range vary the overriding sensor beyond its specified limit and observe the action change of the controlled device.

7.7.3.7 Remove the temperature simulator and restore the temperature sensor.

7.7.4 Testing of single controller operation is included in test work sheets for air handling system control operation tests, WS 5B-3, in the appendix.

7.8 A controller having a second sensor (reset sensor) to reset the control point or a second controller resets the first controller.

7.8.1 Examples:

7.8.1.1 Discharge air temperature of a dual duct heating coil reset by outside air.

7.8.1.2 Discharge air temperature of main cooling coil reset by outside air.

7.8.1.3 Varying space humidity in accordance to outside temperature to avoid condensation.

7.8.2 test procedure:

7.8.2.1 Determine from the project document and the submittals the controlled variable reset schedule (the relationship between the reset index and the controlled variable).

7.8.2.2 Disconnect both reset and primary sensors from the controller (or controllers) and connect two simulators in their place (STP-1, 2, or 3). Instead of temperature, humidity, or duct pressure, the simulator indicates pneumatic pressure, electric resistance, or electric voltage.

7.8.2.3 Manipulate both simulators in accordance to the contract specified or submittal reset schedule. The action of the controlled device should agree with the schedule. Pay special attention to the end points (high and low) of the schedule.

7.8.2.4 Plot the reset schedule from test results and compare with the specified schedule.

7.8.2.5 Restore sensors.

7.8.3 Testing the operation of a controller resetting by a second sensor or by another controller is included in test work sheets for air handling system control operation tests, WS 5B-3, in the appendix.

7.9 Using multiple zone sensors to reset air temperature for heating or cooling.

7.9.1 Systems are usually designed that the zone having the highest load resets the air temperature controller. control signals from each zone sensors are fed into a device (called selector or discriminator) to pick the most desired signal and this signal is used to reset the air temperature controller.

7.9.2 Test procedure:

7.9.2.1 Determine from the project document and the submittals the controlled variable reset schedule (the relationship between the reset index and the controlled variable) and the zones which may reset the controller.

7.9.2.2 Disconnect the primary sensor from the controller and connect a simulator in its place (STP-1, 2, or 3). Instead of temperature, the simulator indicates pneumatic pressure, electric resistance, or electric voltage.

7.9.2.3 Disconnect the first zone sensor and connect a simulator in its place (STP-1, 2, OR 3).

7.9.2.4 Vary the signal level (increasing or decreasing depending upon the design of the control system) and observe the output of the signal selector device. At a certain level of the zone signal it should exert control of the output of the signal selector.

7.9.2.5 Repeat steps 7.9.2.3 and 7.9.2.4 for other zones to confirm the control of signal selector output by zone signals.

7.9.2.6 Manipulate both simulators (primary sensor and the last zone sensor) in accordance to the contract specified or submittal reset schedule. The action of the controlled device should agree with the schedule. Pay special attention to the end points (high and low) of the schedule.

7.9.2.7 Plot the reset schedule from test results and compare with the specified schedule.

7.9.2.8 Restore sensors.

7.9.3 Testing the operation of multiple zone sensors resetting heating or cooling coil air temperature is included in test work sheets for air handling system control operation tests, WS 5B-3, in the appendix.

# CHAPTER 6 BUILDING AUTOMATION SYSTEMS

1. **Scope.** This chapter provides inspection and testing procedures for energy monitoring and control system (EMCS). The procedures are applicable to field inspection and testing of hardware and software of EMCS. Emphasis is placed on sensor calibration, end-to-end data verification, and verification of software logic and calculations. The subcontractor supplying and installing the EMCS should be involved in inspecting and testing of the systems.

## 2. Reference Standards.

a. ANSI Standard C2 - National Electrical Safety Code.

b. ANSI/IEEE Standard C12.1 - Code for Electricity Metering.

c. ANSI/IEEE Standard C57.13 - Instrument Transformers.

d. ANSI Standard X3.4 - National Standard Code of Information Exchange.

e. ANSI Standard X3.64 - Additional Controls for Use with American National Code for Information Interchange.

f. IEEE Standard 142 - Recommended Practice for Grounding of Industrial and Commercial Power Systems.

g. Military Standard MIL-STD-2202 - EMCS Factory Test Procedures.

h. Military Standard MIL-STD-2203 - EMCS Performance Verification and Endurance Test Procedures.

i. NFPA Standard 70 - National Electrical Code.

j. ANSI/ASHRAE Standard 114-1986 - EMCS Instrumentation

## 3. EMCS Inspection.

a. EMCS shall be inspected for construction and installation to meet safety and functional requirements.

b. See EXHIBIT 6-A for inspection procedures and Appendix for inspection check lists.

## 4. EMCS Testing.

a. EMCS shall be tested in the field to meet functional performance requirements of the contract specifications.

b. Individual testing of component performance is not recommended except for sensor calibrations.

c. EMCS sensing accuracies from sensors to display must be verified to meet the specified accuracies.

d. EMCS calculations of sensed variables must be verified to meet the specified accuracies or generally recognized good engineering practices.

d. EMCS application software must be verified to meet the contract specification intent. Software to implement specification intent may vary. The commissioning team must be familiar with the application and revise the described procedures if necessary.

e. Certain tests of automatic temperature controls which may also apply to EMCS functions are described in Chapter 5, AIR HANDLING EQUIPMENT AND SYSTEM. Certain applications of measurement, instrumentation, and calculations are described in Chapter 2, BASIC MEASUREMENT.

f. See EXHIBIT 6-B for test procedures and Appendix for test work sheets.

## EXHIBIT 6-A INSPECTION PROCEDURES FOR BUILDING AUTOMATION SYSTEM (BAS)

1. **Scope.** The inspection procedures described in this EXHIBIT apply to energy monitoring and control systems (EMCS). Certain inspection of localized automatic temperature controls for air handling systems which may also apply to the EMCS are described in EXHIBIT 5-A, INSPECTION PROCEDURES FOR AIR HANDLING SYSTEMS. Certain application precautions of measurement instrumentation are described in CHAPTER 2, BASIC MEASUREMENT.

### 2. Industry standards.

a. ANSI Standard C-2 (National Electrical Safety Code) states rules for practical safeguarding of persons during installation, operation, or maintenance of electric supply and communication lines and their associated equipment which are used in buildings as a utility. Included, among others, are electric supply, telephone, data, fire, and police alarm lines and equipment.

b. IEEE Standard 142 (Recommended Practice for Grounding of Industrial and Commercial Power Systems) describes practices and methods of grounding electric systems and equipment. Included are electric system grounding, equipment grounding, static and lightening grounding, and methods of connection to earth.

c. NFPA Standard 70 (National Electrical Code) describes provisions for safeguarding of persons and property from electricity hazards. This code covers installation of electric conductors and equipment related to building and its occupancy and equipment use. However, it does not cover installation of communication and electric equipment which are under the exclusive use and control of communication and electric utilities.

### 3. Inspection procedures.

3.1 Review contract drawings, specifications, and approved submittals to become familiar with the requirements.

3.2 If existing equipment and systems are interfaced with the new system and the specifications require the contractor to test and report the conditions of the existing equipment and systems, be sure these are performed before starting commissioning process to minimize future possible disputes.

3.3 Verify delivery of training, operating, and maintenance manuals, including materials for display such as control diagrams, slides for projectors, dynamic color graphics of screen copy (or photographs of screen), and source code listing. Manuals must be complete and specifically designed for the project. Control diagrams must be complete and framed with proper item identification, understanble sequence description, etc.

3.4 Inspect equipment for completion, including field equipment and central computer and associated equipment (display, printers, data storage devices, etc.).

3.5 Verify equipment models against approved submittals. Verify that model and serial numbers are provided on major components of equipment. Inspect that the same type of equipment are produced by the same company.

3.6 Inspect for proper installation and omissions of equipment and wiring against drawings, specifications and approved submittals. Support equipment such as PROM programmer, field interface device (FID)/multiplexer (MUX) portable tester, FID and data environment (DE) simulators, if specified, must be supplied.

3.7 Check for access spaces and clearance of equipment. Manufacturer's recommended spaces must be provided.

3.8 Check all electrical connections for tightness.

3.9 Check equipment and wiring for proper grounding. This includes equipment in the field, central computer equipment, and building facility such as raised floor and wire troughs. The requirements of equipment grounding are usually specified in the equipment manufacturer's installation instructions or in codes listed in Section 2 above and should be shown on installation shop drawings. The commissioning team should verify actual installation in the field. Check grounding wire size, installation manner, and insulation integrity for safety.

3.10 Certain signal wiring requires shielding to minimize interference from other electromagnetic sources. If shielding is required from construction documents and shop drawings, verify its existence and grounding of shielding. Generally shielding should continue to the controller, not just the cabinet where the controller is located if line voltage wiring exists in the cabinet. Ground at one end only unless specifically directed otherwise by control manufacturer.

3.11 Check for proper separation of high and low voltage wires, and discrete vs analog wiring if applicable.

3.12 Note bare wires where insulation should be provided.

3.13 Verify wiring and terminals are identified as required in specifications and manufacturer's instructions. Check inside control panels: everything labeled correctly, installed neatly, settings marked, appropriate last-minute notes attached, and all features as specified.

3.14 Check for completeness of required instrumentation and indicating devices. For FID's, specifications may require indicating lights for power, on-line with central control unit (CCU), self test status, FID output disabling status, etc.

3.15 Verify cabinet type (indoor or outdoor) of FID and MUX.

3.16 Verify the type of locking devices of equipment cabinets for specifications compliance. Verify that same key fits all locking cabinets.

3.17 Inspect duct integrity at locations of temperature, humidity, pressure, and flow sensors. Insure that there are no leaks at these locations, especially when located on suction side of the fan.

3.18 Thoroughly examine details of sensor manufacturer's installation and maintenance manual for installation precautions to minimize sensing errors.

3.19 Locations of all sensors are important. They must be located at where the intended measurement of variables can be fully detected.

3.20 Where averaging temperature sensing is needed and/or specified, multiple sensors or averaging sensor must be provided.

3.21 Temperature sensor supporting rods should be well extended in fluid stream to minimize conduction error.

3.22 Inspect temperature sensor location foi possible radiation influence from other equipment. If radiation shield is required, verify its presence.

3.23 Inspect humidity sensor for water.protection. Most humidity sensors must not be in an environment close to or above saturation. Check air baffles for salt-phase transition type sensor if applicable.

3.24 Inspect pressure sensor installation. The relative position of sensing element to stream flow direction is important. Devices to measure static pressure of the flow fluid must not be influenced by flow velocity. For steam sensors, verify that the sensing line includes a pigtail to isolate the steam from the sensor. Verify that the lines are run properly to eliminate any signal error due to sensing line slope, restrictions, etc.

3.25 Similar to pressure sensing devices, all flow sensing devices are sensitive to their relative position to fluid flow direction. The sensing plane of these devices should be inspected in relation to pipe and duct flow direction.

3.26 Flow sensing devices must have minimum pipe length upstream and downstream according to contract specifications, manufacturer' recommended lengths, or other recommended practices (see Chapter 2 BASIC MEASUREMENT).

3.27 Sensors installed in chilled water pipes or vessels should have their support long enough to avoid condensation in electronic parts. Electrical boxes for electronic parts should be oriented to avoid receiving condensation.

3.28 Some sensor transmitters may be influenced by high temperature. Sensor support should be long enough to minimize this effect.

3.29 Inspect mechanism of damper and valve to position sensor. The position should be responsive to damper and valve movement without slippage. Check control element (damper blades/linkages) for smooth operation.

3.30 Verify all controls functioning accurately without hunting.

3.31 Verify completion of specified training programs. This may involve personnel from the building use agency. Contract specifications should be checked as to the steps and scope of the training.

## EXHIBIT 6-B TEST PROCEDURES FOR BUILDING AUTOMATION SYSTEM (BAS)

1. **Scope.** The test procedures described in this EXHIBIT apply to field test of energy monitoring and control systems (EMCS). Certain test of localized automatic temperature controls which may also apply to the EMCS are described in EXHIBIT 5-B, TEST PROCEDURES FOR AIR HANDLING SYSTEMS. Certain application precautions of measurement and instrumentation are described in Chapter 2, BASIC MEASUREMENT.

2. **Industry standards.**

a. Military Standard MIL-STD-2202 (EMCS Factory Test Procedures) presents guidelines for factory test requirements of EMCS using tri-service EMCS guide specifications, before the equipment is shipped to the field for installation. Micro systems are not included.

b. Military Standard MIL-STD-2203 (EMCS Performance Verification and Endurance Test Procedures) presents guidelines for generic test procedures designed to assure that EMCS installed using tri-service EMCS guide specifications meet the specified technical, operational, and performance requirements.

c. ANSI/IEEE Standard C12.1 (Code for Electricity Metering) establishes acceptable performance criteria for ac watthour meters, demand meters, demand registers, pulse devices, instrument transformers, and their auxiliary devices. It also includes information such as recommended measurement standards, installation requirements, test methods, and test schedules of these equipment.

d. ANSI/IEEE Standard C57.13 (Instrument Transformers) covers certain electrical, dimensional, and mechanical characteristics and takes into consideration certain safety features of current and inductively coupled voltage transformers used in the measurement of electricity and control of equipment. It may be used as basis for performance, interchangeability, safety and selection of these transformers.

e. ANSI Standard X3.4 (National Standard Code of Information Interchange) specifies a set of characters with their coded representation for interchange of information among data processing systems and associated equipment, and within data communication equipment. This character set includes control characters for code extension.

f. ANSI Standard X3.64 (Additional Controls for Use with American National Standard Code for Information Interchange) defines a set of control functions that augment the set of control functions in the standard of

e. above.

g. ANSI/ASHRAE 114-1986 (EMCS Instrumentation) deals with accuracy of instrumentation.

## 3. General.

3.1 The size and configuration of EMCS vary considerably for GSA managed projects according to the size and complexity of the mechanical systems, the desire of the owner for system operation, and cost considerations. Therefore, the commissioning team must review the contract documents before any attempt to proceed with testing of EMCS.

3.2 Since all projects require submittal approval and most specifications require factory tests of EMCS equipment before shipping, commissioning tests should be concentrated on verifying functioning and performance in the field. If factory testing for components is specified, the Team should verify the factory test by inspection or obtain proof from the contractor.

3.3 Testing individual performance of EMCS components in the field, except for sensors, is not included in this guide.

3.4 Essentially field testing is divided into three categories: sensor calibration; end-to-end (from sensor to readout devices in central control room) verification of data; and verification of software logic and calculations.

3.5 It is useful, and usually essential, to verify operation of EMCS by forced failures of primary units.

## 4. Test procedures.

4.1 Verify calibration of sensors, sensor/transmitters, and sensor/controllers. This includes temperature, humidity, pressure, flow, and electricity consumption. See Chapter 2, BASIC MEASUREMENT.

4.2 Test system startup operation.

4.2.1 Before the test make sure all EMCS equipment are off.

4.2.2 Turn on all EMCS equipment.

4.2.3 Initiate computer manufacturer's specified startup procedures to start computer operation.

4.3 Verify the existence of contract specified and/or submittal approved software by checking file storage of the computer and/or by actual performance demonstration. Depending on the size and sophistication of the projects, the following software may be required in the central computers:

4.3.1 Bootstrap program to load and initiate computer and EMCS operation.

4.3.2 Disk operating system to manage all peripheral devices and file management.

4.3.3 Editor software to create and modify source codes.

4.3.4 Language processor (compiler or interpreter) to translate source codes to object codes.

4.3.5 Linking software to create relocatable codes.

4.3.6 Assembler for the assembly language translation.

4.4 After initial bootup, and prior to any further checkout, verify backup system operations and switchovers including redundant processors, backup power supplies, battery backed memories, etc. Review manufacturer's software and functional test procedures which were performed at the manufacturer's site. (It is important that in the system specification process a test procedure be requested and that data from that test be submitted prior to delivery of system.) Verify EMCS command software used by building operators from operator's console. This may be checked by issuing commands at the operator's console and observing display, printer output, or HVAC equipment responses. The following features are usually specified in the contract specifications and may be verified as outlined.

4.4.1 Software for checking input commands and issuing error messages. Enter various correct and incorrect commands.

4.4.2 System and point addressing check. Enter command to display I/O data. Verify all data points which are listed in point directory.

4.4.3 Start-stop or enable-disable of HVAC equipment or EMCS components (FIDs AND MUXs). Enter commands to start/stop selected HVAC equipment, and to disable and enable selected FIDs, MUXs, and sensor inputs.

4.4.4 Operator override/automatic mode. Enter command to change selected automatic control under EMCS to manual and vice versa.

4.4.5 Display format. Enter commands to display data and graphics on terminal and graphic display. Check display content for adequacy and clarity as specified.

4.4.6 Ability to modify, cancel and confirm operator's commands. Verify by entering commands.

4.4.7 Set-point adjustment and limiting. Enter commands to adjust set points of controllers and range limits of the controlled media. Verify by display. Also enter commands to adjust set-points outside their range limits. EMCS should display error messages.

4.4.8 System access and access level control. Try to log on to system with both incorrect and correct ID codes. Try to enter different commands with different access level of the operators. The responses of the EMCS should be as specified.

4.4.9 Start/stop equipment. Enter command to start or stop selected equipment. Also reset time to initiate automatic mode. Verify responses by observation of equipment and EMCS display.

4.4.10 Change parameter of points. Enter commands to change parameters of selected points such as high and low limit alarms, scale factor, etc. to test the adequacy of software.

4.4.11 Report generating (status, profile, energy, etc.). Enter commands to generate reports such as all points, trend, total display of a system, timed display, and other specified reports. Examine the report content for general format, system/point code, time interval of reporting, point status/value/unit, energy amount/rate/unit, status of control and set time (manual or automatic), and other specification required information. Verification of software calculations of various reporting values is outlined in section 4.5 (Test EMCS overall performance) below.

4.4.12 Check for proper operation of system status reports, including point status reviews which would include information such as points currently in alarm, points removed from alarm checking, points off of scan, etc.

4.4.13 Alarm reporting. Initiate alarm conditions of different points at different alarm levels in sequence to examine alarm reports. The reports should show alarm location and device, alarm time, cause of alarm, current status of the point, etc. as required in the specifications. When alarm conditions are removed the printer should print updated status report. Also verify audible alarm operations in accordance with specification requirements. Then initiate alarm conditions at different levels at the same time to check alarm priority.

4.5 Test EMCS overall performance. These tests verify the overall accuracy of the EMCS from sensors, signal conditioning, data transmission, etc., as well as software used for certain calculations.

4.5.1 Sensor calibrating instruments should be used in checkout of the overall performance. The sensors of these instruments should be placed at the proximity of EMCS sensors to indicate the conditions of the controlled media (air, water, etc.). A preliminary evaluation should be made as to the suitability of having the EMCS sensors checked in place or they may be placed in simulated environment. If the response times of the two sensors (EMCS sensor and calibration sensor) are similar, it may be performed with the sensors in place. If the conditions of the controlled media change slowly, it may also be performed with the sensors in place. However, if the conditions of the controlled media change rapidly and the time responses of the two sensors vary considerably, the checkout process should be done with the sensors placed in a known environment such as a temperature bath.

4.5.2 For EMCS sensors measuring air or water temperature the checkout may be done with sensors in place, if conditions described in 4.5.1 above are satisfied. Specifications of many projects require that calibration sensor wells be installed in pipes for in place calibration. If calibration wells are not installed in pipes, checkout must be done with a temperature bath.

4.5.3 Ways of communicating (transmitter/receiver, telephone, etc.) between the sensor locations and EMCS central control room are needed to coordinate timing and other calibration information.

4.5.4 Checkout procedures for air, steam, and water temperature, air humidity, air static pressure, and steam pressure with sensors in place.

4.5.4.1 Place calibration sensor in the controlled medium (air, water, or steam). Caution should be exercised that EMCS and calibration sensors do not interfere with each other (such as for temperature or pressure sensing) and that the calibration sensor does sense the true conditions.

4.5.4.2 Wait sufficient time for the calibration sensor to stabilize. The time required depends on the time constant and the initial condition of the sensor.

4.5.4.3 Coordinate time between the site and central control room for taking readings.

4.5.4.4 Simultaneously take readings of the calibration instrument and the EMCS readout terminal.

4.5.4.5 Take at least one more reading for the same sensor. The range of the two readings taken should be as wide as the HVAC operation allows, but not more than that called for in the contract specifications. In order to have the wide range desired the second test may need to be conducted at a different time from the first test when the HVAC equipment experiences different loads.

4.5.4.6 Compare readings from the calibration instrument and the EMCS. They must be within the accuracy requirements of the contract specifications. The values of certain data need to be calculated before comparison. These are specifically noted in the following paragraphs.

4.5.5 Checkout procedures for water and steam temperature with sensors removed from pipes.

4.5.5.1 Remove sensor from pipe and place it in a portable temperature bath.

4.5.5.2 Place calibration sensor in the portable temperature bath. Since temperature is measured at steady conditions during this test, there is no need to concern time constant differences of the two sensors.

4.5.5.3 Set bath temperature to around the contract specified low range of the sensor.

4.5.5.4 Wait sufficient time for sensor temperature to stabilize.

4.5.5.5 Coordinate time between the site and central control room for taking readings.

4.5.5.6 Simultaneously take readings of the calibration instrument and the EMCS readout terminal. These readings give the low range check.

4.5.5.7 Set bath temperature to approximately three-quarters of the contract specified operation range of the sensor.

4.5.5.8 Repeat steps 4.5.5.4 to 4.5.5.6 to get the high range data.

4.5.5.9 Compare both low and high readings from the calibration instrument and the EMCS. They must be within accuracy requirements of the contract specifications.

4.5.6 Checkout procedures for flow measurement.

4.5.6.1 To check flow measurement from end-to-end (from sensor to readout device) in most cases is difficult. The primary flow sensors (such as orifice plates, turbine meters, etc.) must be substituted by sensor simulating instruments which may be manipulated to give known sensing quantities (such as manometer or pressure calibrator for pressure, count generator for turbine meter, etc.).

4.5.6.2 Remove primary flow sensor from EMCS.

4.5.6.3 Connect sensor simulating instrument to EMCS.

4.5.6.4 Manipulate sensor simulating instrument signal to zero flow signal.

4.5.6.5 Take reading from EMCS readout terminal. This reading should show zero flow.

4.5.6.6 Manipulate sensor simulating instrument signal to approximately three-quarters of the high range of the specified flow. Record this data.

4.5.6.7 Take reading from EMCS readout terminal. This is the high range data.

4.5.6.8 Calculate manually the theoretical flow rates from the high simulated data (from differential pressure or counts to flow rate).

4.5.6.9 Compare the manually calculated flow rates (both zero and high) with the readings from the EMCS readout terminal. They must be within the accuracy requirements of the contract specifications.

4.5.6.10 Enter a new constant (say approximately 10% more than the correct constant) in the flow calculation equation of the software. Use the new constant to recalculate the flow rate manually. The newly calculated flow rate should be close to the EMCS indicated flow rate within the specified tolerance.

4.5.7 Check out procedures for enthalpy calculations.

4.5.7.1 Set EMCS to report outdoor temperature, humidity, and enthalpy.

4.5.7.2 Manually calculate enthalpy of the air with one set of temperature and humidity printout using equations given in EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS.

4.5.7.3 Simulated signals of temperature and humidity may also be used to check enthalpy calculations.

4.5.7.4 The difference of the reported enthalpy shall not differ from that of the calculated by more than 3% or, if specified in the specifications, shall be within the accuracy stated in the contract specifications.

4.5.8 Checkout procedures for energy calculations. Instantaneous energy consumption rates and accumulated energy amount are usually included in reports. They should be verified for correctness.

4.5.8.1 For energy consumption using water as medium, obtain a set of operating data from EMCS containing flow rate, temperature differential, and energy amount. Hand calculate energy amount with the flow rate and temperature differential. Verify the hand calculated amount with the indicated amount.

4.5.8.2 For energy consumption using steam as medium, obtain a set of operating data from EMCS containing flow rate, steam pressure, steam temperature, and condensate temperature. Hand calculate enthalpies of steam and condensate (using steam tables), and the net energy amount. The difference between hand calculated and EMCS indicated amounts should be within the specified tolerance.

4.5.8.3 For energy accumulation calculations, set the system to print both instantaneous and accumulated energy data for the same period. The instantaneous data should be printed at very short intervals within the period to be accumulated. Verify the accumulated data (thus the accumulation software) by adding the instantaneous energy amount of the entire period.

4.5.8.4 Verify accumulation data for electric, steam, and water energy.

4.6 Test EMCS application software. EMCS performance and capabilities depends upon how application software is written. Although substantial differences may exist in actual EMCS software being offered today, the following test procedures are considered suitable for testing typical requirements. The commissioning team must examine the contract specifications to be sure what the contract requirements are and compare them with the details of the contractor' submittals. The test procedures described below do not check the details of the software, rather, they try to verify the final output as indicated by the field equipment. Modify the test procedures to suit particular projects as necessary. Before testing each program the required input and output of the program and those listed in the contract specifications should be compared to make sure that the program covers the specified operations. Verification of HVAC equipment operation (such as equipment status or temperature of space air) may be done by either (1) actual observation of equipment status and test instruments, or (2) obtaining EMCS reports if the accuracy of these reports has been verified previously.

4.6.1 Scheduled start-stop program. To start and stop HVAC equipment based on predetermined time of the day and day of the week. Some applications also require time delays for large loads to reduce power surges.

4.6.1.1 Verify that input includes start/stop time and days for specified equipment. Also verify input for time delays of specified equipment. Check holiday effect.

4.6.1.2 Note from operator's console the status of selected equipment which is specified to be on scheduled start-stop program.

4.6.1.3 Enter command to place this equipment under the program.

4.6.1.4 Observe equipment at the scheduled start-stop time to verify its operation. Also verify time delay for large loads.

4.6.1.5 Start and stop this equipment manually by overriding the EMCS control. EMCS should issue alarm for unauthorized action.

4.6.1.6 See WS6B-5 for sample test work sheets.

4.6.2 Optimum start-stop program. To start and stop equipment based on weather and building thermal conditions to optimize equipment running time.

4.6.2.1 Verify that the required input includes space temperature, outdoor temperature, occupied time and days of the week, and the response time of the air handling equipment, on an individual system by system basis.

4.6.2.2 Enter command to place selected equipment under the program.

4.6.2.3 At the beginning and the end of the scheduled occupancy time record the space temperature. These temperatures must not differ by more than 1.7 °C (3 °F) from the required occupied space temperature, or, if specified, by an amount greater than the tolerance specified in original specification.

4.6.2.4 Verify that at the beginning of the occupied time the air handling system is on and ventilation air is being admitted.

4.6.2.5 Start and stop the equipment manually by overriding the EMCS control. EMCS should issue alarm for unauthorized action.

4.6.2.6 See WS6B-6 for sample test work sheets.

4.6.3 Duty cycling program. To shut down equipment during building occupied hours to save energy and reduce demand charge. The cycling time is varied so that the space conditions will be kept within a predetermined temperature and relative humidity band. Minimum on-period and maximum off-period may also be specified.

4.6.3.1 Input required data. This usually include maximum and minimum space temperature, and minimum cycling time.

4.6.3.2 Enter command to place equipment under duty cycling control.

4.6.3.3 Record space temperature at 5 minute intervals.

4.6.3.4 Verify that the equipment is cycling.

4.6.3.5 Input space temperature at different levels and verify cycling time change by observation. Contract specified minimum on-period and maximum off-period must not be violated.

4.6.3.6 Space temperature during duty cycling time must be within the maximum and minimum temperature band.

4.6.3.7 See WS6B-7 for sample test work sheets.

4.6.4 Electrical demand limiting program. This program limits electric load to below utility company demand schedule by shedding certain electric loads. The demand charge depends on the method the utility company uses. Generally, fixed interval metering may shed equipment sequentially or rotationally. The loads which have been shed are restored when the demand becomes lower than a predetermined level. There are many versions of demand limiting. The commissioning team should be familiar with the demand charge method and the contract specification requirement of demand limiting.

4.6.4.1 The contract specification of electrical demand limiting program may require some of the following input: electric loads (equipment) under the program, load priority, demand metering interval, average power during metering interval, delay time, minimum off-time, minimum-on time, and maximum off-time. The time and days applicable may also be included. Check to make sure the contractor supplied input list agrees with required items of the specification.

4.6.4.2 Override demand sensor during testing.

4.6.4.3 Turn on HVAC equipment and/or increase electric load so the target demand will be exceeded.

4.6.4.4 Confirm equipment shut-down by observation of equipment or EMCS report. Record the sequence of shut-down. The sequence must agree with specified priority levels.

4.6.4.5 Selectively decrease equipment load so the target demand will not be exceeded. Confirm the sequence of restoring loads in accordance with priority level (reverse the sequence of shedding).

4.6.4.6 If rotation of shedding equipment in the same priority level is required in the contract specifications, repeat steps in 4.6.4.2 to 4.6.4.4 above to verify the rotation.

4.6.4.7 Verify that the minimum off-time, minimum on-time, maximum off-time, and delay time are not violated for the HVAC equipment which is given these limitations.

4.6.4.8 See WS6B-8 for sample test work sheets.

4.6.5 Day-night setback program. To reduce energy consumption during unoccupied hours by lowering space temperature in the heating season and raising space temperature in the cooling season.

4.6.5.1 Verify the input parameters of the software. They usually include time and day of the setbacks, and the space temperature during the setbacks.

4.6.5.2 For heating setback test, change the setback time from occupied to unoccupied (setback) time. The HVAC system should respond to setback mode. If it is an air handling system, the outside air damper should close and the fan should cycle to maintain the setback temperature.

4.6.5.3 Change the setback temperature to slightly higher than the current space temperature. The system should operate to reach and maintain the setback temperature. During this period the outside air damper should remain closed regardless of the fan operation.

4.6.5.4 After the system operation in 4.6.5.3 above is confirmed, change the setback time to the correct occupied time. The system should now be in the occupied mode and the fan and damper should operate accordingly as specified.

4.6.5.5 For cooling setback test, repeat steps 4.6.5.2 to 4.6.5.4 above, except that in step 4.6.5.3 the setback temperature for unoccupied period is set to slightly lower than the current space temperature so the cooling system will be in operation during the test.

4.6.5.6 See WS6B-9 for sample test work sheets.

4.6.6 Dry bulb economy cycle program. Dry-bulb air temperatures are used as indices to utilize outdoor air for free cooling. There are different versions of dry bulb economy cycles. However, they all compare outside air temperature with a changeover temperature. The commissioning team should review the contract specifications and be familiar with the scheme of dry bulb economy cycle being used. Under EXHIBIT 5-B TEST PROCEDURES FOR AIR HANDLING SYSTEMS a procedure is outlined for testing economy cycle controls by using temperature simulators to simulate certain temperature sensors. That procedure may also be used to test EMCS economy cycles. Since the changeover temperature setting may easily be changed from the operator's console in an EMCS, the following procedure is provided as an alternate for dry bulb economy cycle test and is considered as more suitable for EMCS.

4.6.6.1 Verify that the contract specification required inputs are included in the EMCS input. They usually are the outdoor air, the return air, the mixed air, and the change-over temperatures.

4.6.6.2 Request a report on current status of the air handling unit and examine the outdoor temperature, the return air temperature, the mixed air temperature, the change-over temperature, the outside air damper position, and the return air damper position.

4.6.6.3 If the outdoor temperature is higher than the change-over temperature, the outside air damper should be at its minimum position. If the outdoor temperature is lower than the change-over temperature, the damper control should be under local control and the mixed air temperature should be as required by the specifications. The return air damper position should be confirmed to complement the outdoor air damper position. In most projects the heating and the cooling coil controls also depend upon the relationship of the outdoor and the change-over temperatures so a maximum amount of mechanical cooling may be saved. Therefore, coil valve positions should also be verified.

4.6.6.4 Change the change-over temperature setting from that of condition in 4.6.6.3 to the other side (higher or lower) of the outdoor temperature and confirm the positions of the outdoor air and the return air dampers, and the positions of the coil valves.

4.6.6.5 See WS6B-10 for sample test work sheets.

4.6.7 Enthalpy economy cycle program. Air temperature and humidity are used as indices to utilize outside air for free cooling. Since enthalpy economy cycle senses actual temperature and humidity of both outdoor air and return air to make control decisions, temperature and humidity simulators or a portable temperature bath are needed to create the temperature and/or humidity conditions desired. Test of this program should confirm the outdoor air and return air damper actions and the correctness of the enthalpy calculations.

4.6.7.1 Confirm that the temperature and humidity of both outdoor air and return air are included in the input of the program.

4.6.7.2 Request a report on current status of the air handling unit and examine the outdoor temperature, outdoor humidity, outdoor enthalpy, return air temperature, return air humidity, return air enthalpy, and outside air and return air damper positions.

4.6.7.3 Compare the enthalpies of outdoor air and return air from the report. Verify the correctness of damper positions.

4.6.7.4 Remove outdoor temperature and humidity sensors from EMCS and substitute with temperature and humidity simulators to change the indicated outdoor enthalpy. An alternative way is to immerse the outdoor temperature sensor in a portable temperature bath. However, it is difficult to accurately produce a desired outdoor humidity in the field. Therefore, if the latter method is used to alter the outdoor enthalpy, the test may need to be prolonged for weather change. To proceed with the test, set the outdoor temperature (simulator or bath) and humidity (simulator) to different levels. The enthalpy regions to be checked are detailed in TEST PROCEDURES FOR ECONOMY CYCLE section of EXHIBIT 5-B TEST PROCEDURES FOR AIR HANDLING SYSTEMS. In each of the enthalpy regions the enthalpy of the outside air and the return air must be reported and compared to confirm the outdoor damper positions. A psychrometric chart to visually locate the outside air and return air conditions is helpful during this test.

4.6.7.5 After completing of test restore outdoor temperature and humidity sensors to their original places.

4.6.7.6 See WS6B-11 for sample test work sheets.

4.6.8 Ventilation air control program. To reduce energy consumption during warm-up or cool-down periods by cutting off outdoor air. However, some contract specifications (in some geographic areas of the country) may require outdoor dampers be open during warm-up/cool-down periods when the outdoor air is warmer/cooler than the space temperature. The commissioning team should be familiar with the contract requirements.

4.6.8.1 Verify that the program requires and includes input of equipment start/stop time and day, occupied/unoccupied time schedule, and space temperature.

4.6.8.2 It is assumed that this test is being conducted during occupied period. Confirm that the outdoor damper is admitting outdoor air.

4.6.8.3 Change the occupied/unoccupied schedule to put the system about 15 minutes before occupied period.

4.6.8.4 The outside air damper and the return damper positions depend on relationship of the outdoor and the return air temperatures and whether the system is in the heating or cooling mode at the time of test.

4.6.8.5 If the system is in the heating mode and the outdoor temperature is higher than the space temperature, the heat of the outdoor air may be used to heat the space, and the dampers should be under local loop control. Otherwise, the outdoor damper should be closed so energy is not wasted to heat the outdoor air. Therefore, the space temperature setting should be altered during the test so it will be higher and lower than the outdoor temperature during the course of the test. The damper positions should be verified during the test to comply with the control logic of the software program.

4.6.8.6 Similar procedures should be used to test the operation of the outdoor and the return air dampers for cooling mode.

4.6.8.7 See WS6B-12 for sample test work sheets.

4.6.9 Heating/cooling coil temperature reset program. To reset heating coil discharge temperature (hot deck) lower or to set cooling coil discharge temperature (cold deck) higher in accordance to certain indices to save coil energy. Certain programs also sense air humidity to give upper cooling coil reset temperature values. The heating/cooling coil temperature reset program is especially important in multi-zone or dual-duct systems where hot air and cold air are mixed to satisfy space loads.

4.6.9.1 Verify required input data. These data may include upper and lower hot deck temperatures for heating, upper and lower cold deck temperatures for cooling, index temperature to reset hot deck or cold deck temperature, and maximum allowed space humidity. Outdoor air temperature or space temperature is usually used as the index temperature.

4.6.9.2 Substitute the index temperature sensor with a temperature simulator or place it in a portable temperature bath.

4.6.9.3 Vary the index temperature output by either manipulate the simulator or by varying the bath temperature. Verify hot deck or cold deck temperature change. The deck temperature should change in the opposite direction as the index temperature changes. However, the deck discharge temperature should not go beyond the specified upper and lower temperature limits.

4.6.9.4 To test cold deck programs which limit the space humidity level, set the space humidity limit slightly below the actual space humidity (depending on system design it may be the return air humidity). Repeat step 4.6.9.3 above and observe the cold deck temperature. The cold deck temperature should decrease.

4.6.9.5 See WS6B-13 for sample test work sheets.

4.6.10 Reheat system reset program. To reset cooling coil discharge air temperature of a reheat system in accordance with space load. This program is very similar to the cold deck reset program described in (9) above.

4.6.10.1 Verify required input data. This may include upper and lower cold deck temperatures, index temperature for resetting, and maximum allowed space humidity. Outdoor air temperature or space temperature is usually used as the index temperature.

4.6.10.2 Substitute the index temperature sensor with a temperature simulator or place it in a portable temperature bath.

4.6.10.3 Vary the index temperature output by either manipulating the simulator or by varying the bath temperature. Verify coil discharge temperature changes. The coil temperature should change in the opposite direction as the index temperature changes.

4.6.10.4 Set the space humidity limit slightly below the actual space humidity (depending on system design it may be the return air humidity). Repeat step 4.6.10.3 above and observe the cooling coil discharge temperature. This temperature should decrease.

4.6.10.5 See WS6B-13 for sample test work sheets.

4.6.11 Hot water temperature reset program. To reset hot water temperature in accordance to heating load changes. In most cases the outdoor air temperature is used as the index to lower water temperature as the outdoor air temperature increases.

4.6.11.1 Verify required input data. This may include outdoor air temperature, the relationship of hot water temperature and outdoor air temperature (reset schedule), and the maximum and minimum water temperatures.

4.6.11.2 Substitute the outside air temperature sensor with a temperature simulator or place it in a portable temperature bath.

4.6.11.3 Vary the outdoor air temperature output by either manipulating the simulator or by varying the bath temperature. Verify hot water supply temperature changes. The water temperature should change in accordance with the reset schedule.

4.6.11.4 Change the outdoor air temperature simulator or temperature bath to 2.8 °C (5 °F) higher than the high end of the reset schedule. Verify that the hot water temperature is not lower than the minimum water temperature in the reset schedule.

4.6.11.5 Change the outdoor air temperature simulator or temperature bath to °C (5 °F) lower than the low end of the reset schedule. Verify that the hot water temperature is not higher than the maximum water temperature in the reset schedule.

4.6.11.6 See WS6B-14 for sample test work sheets.

4.6.12 Boiler sequencing program. To sequence boilers in a multi-boiler plant under varying load conditions for achieving optimum plant efficiency.

4.6.12.1 Verify required input data. This may include heating value of fuel, fuel consumption rate, energy output rate, and boiler sequencing schedule. Steam pressure, temperature, and boiler feed water temperature may also be required for steam boilers. Hot water supply and hot water return temperatures are needed for water boilers. The output of the program should show boiler efficiency data and boiler sequencing schedule (on/off status of boilers).

4.6.12.2 In order to have the highest efficiencies at all building load conditions, the boiler efficiency profile ( efficiency vs. load) of each boiler must be known. Since this information may not be known to the EMCS contractor at the time of commissioning, it may be difficult to perform a true verification of this application software, i.e. to verify that the plant is producing the highest efficiency at all load conditions. Therefore, the test procedure described here is limited to verifying the indicated boiler operation against the programmed boiler operation.

4.6.12.3 Manipulate the EMCS sensing parameter of the plant output or building load, i.e. the flow rate of steam or hot water (depending on system design, the inlet and outlet temperature of hot water system may be appropriate). The plant output or building load is gradually increased from minimum load to full load.

4.6.12.4 While changing the load as described in 4.6.12.3 above, verify boiler sequencing. The boiler on-off status and alarm conditions as indicated by EMCS must agree with that programmed in the software.

4.6.13 Chilled water temperature reset program. To reset chilled water temperature during low load or less critical cooling periods. This program is usually done by sensing space temperature or sensing chilled water coil valve position to reset chilled water temperature while monitoring indoor humidity levels.

4.6.13.1 Verify required input data. This may include chilled water valve position (or control signal to valve), chilled water temperature low limit, chilled water temperature, space temperature high limit, space temperature and humidity, and space humidity high limit.

4.6.13.2 If space temperature is used to reset chilled water temperature, substitute the temperature sensor with a temperature simulator or place the sensor in a portable temperature bath. Manipulate the temperature simulator or the temperature bath controls to raise temperature. Verify that the chilled water temperature decreases or increases as required by the specifications.

4.6.13.3 If chilled water valve position or control signal to valve is used to reset chilled water temperature, manipulate the position sensor to simulate opening of valve (increasing load). Verify that the chilled water temperature decreases.

4.6.13.4 Continue the action described in 4.6.13.2 or 4.6.13.3 above. Verify that the chilled water temperature does not decrease below the low limit of the specified chilled water temperature.

4.6.13.5 Reverse the direction of space temperature or valve position (or control signal to valve) as indicated in 4.6.13.2 or 4.6.13.3 and 4.6.13.4 above. Verify that the chilled water temperature increases, yet it does not raise above the specified high limit specified for the chilled water temperature.

4.6.13.6 Substitute the space humidity sensor with a humidity simulator. Increase the simulated space humidity. Verify that when the simulated humidity is higher than the specified high limit, as entered in the program, the chilled water temperature decreases.

4.6.13.7 The design of the EMCS may sense air temperature or valve positions (or control signal to valve) of more than one zone or HVAC system and select the highest demand zone or system to reset the water temperature. All zone or system sensors (temperature or position or control signal) must be tested in sequence and verified as outlined above.

4.6.13.8 See WS6B-15 for sample test work sheets.

4.6.14 Condenser water temperature control program. To reset the condenser water temperature from a fixed temperature downward, when the outdoor wet bulb temperature is lower, to produce lower condenser water temperature. This reduces the energy consumption of the chiller.

4.6.14.1 Verify required input data. The data may include condenser water temperature, relationship of outdoor wet bulb temperature and condenser water temperature, condenser water temperature low limit, outdoor temperature and outdoor humidity.

4.6.14.2 Substitute outdoor temperature and outdoor humidity sensors with temperature and humidity simulators. Manipulate simulators to produce successively lower wet bulb temperatures. Verify that the condenser water temperature decreases.

4.6.14.3 When the simulated outdoor wet bulb temperature is lower than the low limit of condenser water temperature/wet bulb relationship, the condenser water temperature should not go below the low limit. Verify this requirement.

4.6.14.4 Verify the relationship between the outdoor wet bulb temperature and the condenser water temperature by referring to the cooling tower data or contacting the cooling tower manufacturer. This relationship is normally referred to as "the approach temperature". A 3.9 °C

(7 °F) temperature differential, or approach temperature, is usually specified.

4.6.14.5 See WS6B-16 for sample test work sheets.

# CHAPTER 7 FIRE SAFETY AIR MOVING SYSTEMS

1. **Scope.** This chapter provides inspection and testing procedures for fire safety functions associated with air moving systems including heating, ventilating, and air conditioning (HVAC) systems. These systems may be with or without smoke control capabilities, systems specifically dedicated to zone smoke control, or systems for stairtower pressurization.

## 2. Reference Documents.

a. ASHRAE Standard 15 - Safety Code for Mechanical Refrigeration.

b. ASHRAE Manual - Design of Smoke Control Systems for Buildings.

c. ASTM Standard E136 - Standard Method of Test for Noncombustibility of Elementary Materials - 1973 (note: the standard has been changed but version referenced here is that referenced by NFPA 90A).

d. NBSIR 75-673 - Development of a Fire Test Method for Flexible Connectors in Air Distribution Systems.

e. NFPA Standard 31 - Standard for the Installation of Oil Burning Equipment.

f. NFPA Standard 54 (ANSI Z223) - National Fuel Gas Code.

g. NFPA Standard 70 - National Electrical Code.

h. NFPA Standard 72E - Standard on Automatic Fire Detectors.

i. NFPA Standard 90A - Standard for Installation of Air Conditioning and Ventilating Systems.

j. NFPA Standard 92A - Recommended Practice for Smoke Control Systems (draft document).

k. NFPA Standard 255 - Standard Method of Test of Surface Characteristics of Building Materials.

l. NFPA Standard 259 - Standard Test Method for Potential Heat of Building Materials.

m. GSA ORDER PBS P 5900.2B - Accident and Fire Protection-General.

n. UL Standard 181 - Standard for Factory-Made Air Ducts and Connectors.

o. UL Standard 555 - Standard for Fire Dampers and Ceiling Dampers.

p. UL Standard 555S - Standard for Leakage Rated Dampers for Use in Smoke Control Systems.

q. UL Standard 900 - Standard for Test Performance of Fan Filter Units.

## 3. Inspection of Fire Safety Aspects of Air Moving Systems.

3.1 Air Moving systems shall be inspected to verify that the fire safety requirements of the contract documents pertaining to materials and installation have been fulfilled. The fire safety features of air moving systems must be designed and specified in accordance with GSA Order PBS P5900.2B, Accident and Fire Protection-General. This order requires that air conditioning systems be in accordance with NFPA 90A with some specific exceptions.

3.2 See EXHIBIT 7-A for inspection procedures and Appendix for check lists for HVAC systems with and without zoned smoke control and for stairtower pressurization systems.

## 4. Testing of Fire Safety Aspects of Air Moving Systems.

4.1 Systems for zoned smoke control and systems for stairtower pressurization shall be tested in the field to verify that they meet the requirements of the contract documents. HVAC systems do not require testing.

4.2 See EXHIBIT 7-B for testing requirements for zoned smoke control systems that are either part of an HVAC system or are dedicated for smoke control only.

4.3 See EXHIBIT 7-C for treating requirements for stairtower pressurization systems.

## EXHIBIT A FIRE SAFETY INSPECTION PROCEDURES FOR AIR MOVING SYSTEMS

1. **Scope.** The inspection procedures described in this EXHIBIT apply to the fire safety of systems for heating, ventilating, and air conditioning (HVAC) with or without smoke control capabilities or to systems only dedicated to controlling smoke in building fires. This procedure is intended for HVAC systems that are in accordance with the 1985 version of NFPA 90A. The levels of performance, standards, test methods and other requirements listed in this procedure are consequences based upon its foundation in the 1985 version of NFPA 90A. This procedure is intended as an example inspection procedure, and it is anticipated that users will modify the procedure to suit their needs.

### 2. Reference standards

a. ASHRAE 15 (Safety Code for Mechanical Refrigeration) is intended to assure the safe design, construction, installation, operation, and inspection of refrigeration systems. Among other safety features and precautions, this standard describes requirements of pressure-limiting devices and pressure-relief protection, including installation requirements of refrigeration piping and machinery room housing refrigerating equipment.

b. ASTM E136 (Standard Method of Test for Noncombustibility of Elementary Materials - 1973) is a test method for determination of noncombustibility of elementary materials, to indicate those materials which do not act to aid combustion or add appreciable heat to an ambient fire. It is not intended to apply to laminated or coated materials. (note: the standard has been changed but version referenced here is that referenced by NFPA 90A)

c. NBSIR 75-673 (Development of a Fire Test Method for Flexible Connectors in Air Distribution Systems) is a test method which evaluates the fire performance of a flexible duct connector in terms of: (a) resistance of the flexible connectors to failure by direct fire penetration, (b) adequacy of attachment method of the flexible connector to the duct, and (c) effectiveness of the blocking (firestopping) of the penetration through a fire-rated floor and ceiling.

d. NFPA 31 (Standard for the Installation of Oil Burning Equipment) applies to oil-fired stationary equipment including residential, commercial and industrial steam, hot water plants, and warm air heating plants.

e. NFPA 54 (ANSI Z223, National Fuel Gas Code) is a safety code which applies to the installation of fuel gas piping systems, fuel gas utilization equipment and related accessories. Among the areas this code addresses are piping design, piping materials, piping components, piping installation, piping testing, equipment installation, and equipment venting.

f. NFPA 70 (National Electrical Code) applies to the installation of electric conductors and equipment within public and private buildings, and the code contains provisions considered necessary for safety to life and property. This code addresses wiring design, protection, methods, and materials. Also addressed are electrical equipment, special occupancies, and communication systems.

g. NFPA 72E (Standard on Automatic Fire Detectors) provides basic minimum requirements for the performance of automatic fire detectors with the intent of ensuring timely warning for the purposes of life safety and property protection. The kinds of fire detectors addressed include heat sensing, smoke sensing, flame sensing, and gas sensing. The standard addresses installation, maintenance and testing of detectors.

h. NFPA 90A (Standard for the Installation of Air Conditioning and Ventilating Systems) prescribes minimum fire safety requirements for systems for the movement of environmental air within structures. This standard addresses aspects of fire safety for these systems in detail including definitions, system components, impact on fire integrity of building construction, and controls.

i. NFPA 255 (Standard Method of Test of Surface Characteristics of Building Materials) is a method of testing the surface burning characteristics of building materials to determine comparative characteristics by evaluating the flame spread over the surface and the density of smoke produced.

j. NFPA 259 (Standard Test Method for Potential Heat of Building Materials) is a test to determine, under controlled laboratory conditions, the heat released from a material under fire conditions.

k. UL 181 (Standard for Factory-Made Air Ducts and Connectors) is a standard test method for air ducts and connector systems. The air ducts and connectors covered by this standard include preformed lengths of flexible or rigid ducts, materials in the form of boards for field fabrication of lengths of rigid ducts, and preformed flexible connectors. The method includes tests for surface burning characteristics, flame resistance, flame penetration, burning, corrosion resistance, mold resistance, temperature resistance, puncture resistance, static load resistance, impact resistance, erosion resistance, pressure resistance, collapse resistance, tension resistance, bending resistance, leakage resistance. Air ducts are classified as Class 0, Class 1 or Class 2. This standard requires that installation instructions be supplied by manufacturers.

l. UL 555 (Standard for Fire Dampers and Ceiling Dampers) is a test method applicable to fire dampers and ceiling dampers intended for installation in floor-ceiling and roof-ceiling assemblies. The test method includes construction requirements and tests for fire endurance, hose-stream exposure, closing reliability, duct loading exposure, salt-spray exposure, and spring closing force. Fire dampers are rated at 3/4 hr, 1 hr, 1-1/2 hr, and 3 hr. Ceiling dampers are not assigned hourly ratings, but rather are assembly components designed for use in specific hourly rated resistive assembles. The standard requires that manufacturers supply installation instructions for these dampers.

m. UL 555S (Standard for Leakage Rated Dampers for Use in Smoke Control Systems) is a test method for leakage rated dampers intended for use in heating, ventilating, and air conditioning systems. The test method includes construction requirements and tests for cycling, temperature degradation, duct loading exposure, salt-spray exposure, and air leakage. These smoke dampers are classified as 0, I, II, III, or IV leakage rated dampers, and they are tested at 250 'F or at an elevated temperature selected in increments of 100 'F above 250 'F.

n. UL 900 (Standard for Test Performance of Fan Filter Units) presents test requirements of air filter units of both washable and throwaway types. Filter units are subjected to a flame-exposure test and a spot-flame test. Filter units are classified as either Class 1 or Class 2.

## 3. General inspection procedures.

3.1 Check ducts to verify that materials of duct construction are as specified. Ducts may be constructed of iron, steel, concrete, masonry or clay tile. For ducts constructed of other materials, check that they are Class 0 or Class 1 ducts as specified and that they are tested in accordance with UL 181, Standard for Factory-Made Air Ducts and Connectors. The duct class is imprinted on it by the manufacturer.

3.2 Check duct installation. Duct installation including the hangers must not reduce the fire resistance rating of structural members and of assemblies. Frequently, structural members and assemblies have fire protective coverings, such as drywall construction or a sprayed-on layer. Check that ducts are installed in such a manner that these protective coverings are not damaged. Check that clearance from ducts to combustible construction is in accordance with NFPA 90A. In addition, check that where ducts pass through walls, floors, or partitions the openings in construction around the ducts are in accordance with NFPA 90A.

3.3 Check installation and materials of duct connectors and flexible duct connectors. Class 1 or Class 2 duct connectors tested in accordance with UL 181, Standard for Factory-Made Air Ducts and Connectors, may be used subject to limitations of NFPA 90A. The class is imprinted on the duct connector by the manufacturer. Duct connectors must not exceed 14 ft in length, and they must not pass through floors of buildings. Flexible duct connectors meeting a 1-hour fire exposure, as set forth in NBSIR 75-673, Development of a Fire Test Method for Flexible Connectors in Air Distribution

Systems, may pass through one floor to connect ducts with air terminal units subject to the limitations of NFPA 90A including firestopping around openings. Flexible duct connectors must not exceed 14 ft in length. CAUTION: Because the characteristics of duct connectors and flexible duct connectors are different, one should not be substituted for the other.

3.4 Check duct coverings and linings to verify that their fire safety requirements are as specified. Coverings and linings must be in accordance with the requirements of NFPA 90A. Check that duct coverings do not conceal any service opening.

3.5 Check direct access and inspection provisions. A service opening or a telescoping or removable duct section are used for direct access and inspection. Check that a service opening or a telescoping or removable duct section is provided in ducts adjacent to fire dampers, smoke dampers and smoke detectors. Check that these access openings are identified with letters no less that 0.0127 m (1/2 inch) in height which identify the fire protection device within. Check that service openings are provided in horizontal ducts and plenums where required by contract documents.

3.6 Check plenums between ceilings and floors. Check materials exposed to air flow in these plenums to verify that these materials have smoke developed ratings not greater than 50 and are non-combustible or limited combustible except for electrical wiring, electrical equipment, optical fiber cable and pneumatic tubing. Check that electrical wiring and equipment in plenums is installed in accordance with NFPA 70, National Electrical Code. Check that optical fiber cable in plenums conforms to provisions of NFPA 70, National Electrical Code, or is listed as having adequate fire-resistant and low smoke producing characteristics. Check that pneumatic tubing for control systems is listed as having adequate fire-resistant and low smoke producing characteristics.

The following notes are provided for the convenience of the user of this inspection method, however, in matters of contract compliance or code requirements the definitions and wording of NFPA 90A apply:

3.6.1 A smoke developed rating of a material refers to a number or classification of a material obtained according to NFPA 255, Standard Method of Test of Surface Characteristics of Building Materials, which measures visible smoke.

3.6.2 A non-combustible material is a one which, in the form in which it is used and under the conditions anticipated, will not ignite, support combustion, or release flammable vapors when subjected to fire or heat. Many common materials such as iron, steel, aluminum, concrete, masonry and clay tile are non-combustible. Materials reported as non-combustible, when tested in accordance with ASTM E136, Standard Method of Test for Noncombustibility of Elementary Materials, are considered non-combustible materials.

3.6.3 A limited combustible material is one not complying with the requirements of a non-combustible material, which, in the form in which it is used, has a potential heat value not exceeding 8140 kJ/kg (3500 Btu/lb) (see NFPA 259, Standard Test Method for Potential Heat of Building Materials) and complies with one of the following paragraphs (a) or (b). Materials which decrease in fire performance due to age or usage are considered combustible materials.

3.6.3.1 Materials having a structural base of non-combustible material, with a surfacing not exceeding a thickness of 0.00318 m (1/8 inch) which has a flame spread rating not greater than 50.

3.6.1.2 Materials other than described in 3.6.3.1, having neither a flame spread rating greater than 25 nor evidence of continued progressive combustion, and of such composition that surfaces that would be exposed by cutting through the material on any plane would have neither a flame spread rating greater than 25 nor evidence of continued progressive combustion.

3.6.4 The flame spread rating of a material refers to a number or classification of a material obtained in accordance with NFPA 255, Standard Method of Test of Surface Characteristics of Building Materials.

3.7 Check air filters. Check air filters to verify that they have the classification required by the contract documents and that they have been rated in accordance with UL 900, Standard for Test Performance of Fan Filter Units.

3.8 Check that exposed fan inlets are protected with metal screens in accordance with contract documents to prevent the entry of paper, trash, and similar foreign material.

3.9 Check that heating and cooling equipment is installed in accordance with manufacturers' instructions and the following applicable standards:

| Description | Standard |
|---|---|
| Mechanical refrigeration used with air duct systems | ASHRAE 15, Safety Code for Mechanical Refrigeration |
| Gas fired heating furnaces combined with cooling units in the same duct | NFPA 54 (ANSI Z223), National Fuel Gas Code |
| Oil fired heating furnaces combined with cooling units in the same duct | NFPA 31, Standard for the Installation of Oil Burning Equipment |
| Electrical duct heaters | Part F, Duct Heaters, of Article 424 of NFPA 70, National Electric Code |

3.10 Check the location, fire protection rating and installation of fire dampers. Check that fire dampers are located at all places where they are required by the contract documents. Check the label attached to the fire dampers to verify that they meet the fire protection rating specified by the contract documents and that the damper has been tested in accordance with UL 555, Standard for Fire Dampers and Ceiling Dampers. Check that fire dampers have been installed in accordance with the conditions of their listing and the manufacturer's installation instructions which are supplied with the damper. Further check installation by removing fusible link (where applicable) and operating damper to verify that it closes fully. It is desirable to operate dampers with normal air flow to assure that they are not held open by the air stream. Remember to reinstall all fusible links that have been removed during inspection.

3.11 Check the location, fire protection rating and installation of ceiling dampers. Check that ceiling dampers are located at all places where they are required by the contract documents. Check the label attached to the ceiling dampers to verify that they are appropriate for the floor-ceiling or roof-ceiling assembly in which they are used and that the damper has been tested in accordance with UL 555, Standard for Fire Dampers and Ceiling Dampers. Check that ceiling dampers have been installed in accordance with the conditions of their listing and the manufacturer's installation instructions which are supplied with the damper. Further check installation by removing fusible link (where applicable) and operating damper to verify that it closes fully. It is desirable to operate dampers with normal air flow to assure that they are not held open by the air stream. Remember to reinstall all fusible links that have been removed during inspection.

3.12 Check the location, fire protection classification and installation of smoke dampers. Check that smoke dampers are located at all places where they are required by the contract documents. Check the label attached to the smoke dampers to verify that they meet the leakage and temperature class specified by the contract documents and that the damper has been tested in accordance with UL 555S, Standard for Leakage Rated Dampers for Use in Smoke Control Systems. Check that smoke dampers have been installed in accordance with the conditions of their listing and the manufacturer's installation instructions. During normal system operation, check that each smoke damper required by the contract documents to be closed is fully and tightly closed, and that each smoke damper required to be opened is fully opened.

3.13 Check the location, fire protection rating and installation of combination fire and smoke dampers. Check that combination fire and smoke dampers are located at all places where they are required by the contract documents. Check the label(s) attached to the combination fire and smoke dampers to verify that they meet the fire protection rating specified by the contract documents and that the damper has been tested in accordance with UL 555, Standard for Fire Dampers and Ceiling Dampers. Also, check the label to verify that they meet the leakage and temperature class specified by the contract documents and that the damper has been tested in accordance with UL 555S, Standard for Leakage Rated Dampers for Use in Smoke Control Systems. Check that combination fire and smoke dampers have been installed in accordance with the conditions of their listing and the manufacturer's installation instructions. Further check installation by removing fusible link (where applicable) and operating damper to verify that it fully closes. It is desirable to operate dampers with normal air flow to assure that they are not held open by the air stream. Remember to reinstall all fusible links that have been removed during inspection.

## 4. Controls for systems without smoke control capability.

4.1 Check manual controls. Check that each air distribution system has manually operated device(s) that will stop the operation of supply, return, and/or exhaust fan(s) in an emergency, and that this device is located as specified. With the system in normal operating mode, operate each manual shutdown device, and check that all fans required by the contract documents to be stopped have actually stopped. Also, check that any smoke dampers required by the contract documents to be closed are fully and tightly closed.

4.2 Check automatic controls. If automatic shutdown capability is required, check that the air system has automatic shutdown capability. Check that detectors used to activate any automatic shutdown are located as specified, are of the type as specified, and are installed in accordance with NFPA 72E, Standard on Automatic Fire Detectors. Where applicable, check system shutdown by detectors located in supply duct, return duct, and by detector system installed in the building. With the system in normal operating mode, activate the detector (where applicable) in the return air stream. Check that all fans required by the contract documents to be stopped have actually stopped. Also, check that any smoke dampers required by the contract documents to be closed are fully and tightly closed.

## 5. Controls for systems with zoned smoke control capability.

5.1 Check manual controls. Check that devices required by the contract documents for manual activation and deactivation of the zoned smoke control system have been installed (a detailed check of the functioning of manual control is included in EXHIBIT B).

5.2 Check automatic controls. Check that devices required by the contract documents for automatic activation and deactivation of the zoned smoke control system have been installed (a detailed check of the functioning of automatic control is included in EXHIBIT B).

## EXHIBIT B TEST PROCEDURES FOR ZONED SMOKE CONTROL SYSTEMS

1. **Scope.** The test procedures described in this EXHIBIT apply to zoned smoke control systems that are either dedicated systems or part of systems for heating, ventilating, and air conditioning (HVAC). These procedures should be thought of as an initial effort to develop information which could be of use to engineers and code officials tasked with determining the acceptability of a zoned smoke control system. It is anticipated that users will want to modify the methods to suit their specific needs.

2. **General references.**

a. ASHRAE manual "Design of Smoke Control Systems for Buildings" by Klote and Fothergill consolidates and systematically presents data and calculation procedures necessary to smoke control systems designers and discusses design criteria. Included are discussions of the driving forces of smoke movement, the principles of smoke control, calculation of effective flow areas, concept of symmetry, and design parameters. A computer program for analysis of smoke control systems is presented. Concepts of stairwell pressurization and zoned smoke control are presented.

b. NFPA 92A, Recommended Practice for Smoke Control Systems. This document provides recommendations about design, installation, testing, operation, and maintenance of new and retrofitted mechanical air conditioning and ventilation systems for the control of smoke.

3. **Emergency power.** If standby power or other emergency power has been provided for the operation of the zoned smoke control system, acceptance testing shall be conducted with emergency power and normal power.

4. **Smoke control diagram.** Identify the exact location of each smoke control zone. If it is not part of the building plans, make a smoke control zone diagram of the building. This diagram should include the locations of all zone boundaries and of all doors in those boundaries.

5. **Normal operation test.** With all building HVAC systems in normal operation, the zoned smoke control system shut off, and the smoke barrier doors closed; measure and record the pressure differences across each smoke barrier door. Evaluate these pressure differences to determine that they are appropriate for the balanced HVAC system.

**6. Smoke mode test.** Each smoke zone is to be individually tested by performing the following sequence.

6.1 Activate smoke control system operation in the zone. This should be accomplished by putting one of the detectors into alarm that are intended to activate the smoke control system in that zone.

6.2 Check that the operation of fans is as required by the contract documents.

6.3 Check that the position of smoke dampers is as required by the contract documents. Also, check that any smoke dampers required to be closed are fully and tightly closed.

6.4 Check to verify that all doors required by the contract documents to be closed during smoke control system operation are fully closed and that they operate freely allowing use during evacuation without becoming jammed in their door frames. This should include doors in the boundary of the smoke zone being tested.

6.5 Measure and record pressure differences across all closed doors in the boundary of the smoke zone being tested. Pressure differences resulting from air flowing to the smoke zone being tested are to be recorded as positive values, and pressure differences resulting from air flowing from the smoke zone being tested are to be recorded as negative values.

6.6 Check that the measured pressure difference is within the acceptable range as defined in the contract documents. If the pressure difference is not in the acceptable range, double check that the state of fans, dampers and doors is as required. If any of these is not as required, they should be fixed and the zone retested. After this, if the pressure difference is not acceptable, the flow rates of air to and from the smoke zones in question should be measured and adjusted as appropriate. If the pressure differences are too low after these actions, excessive air leakage paths in the construction should be filled, caulked or sealed as appropriate. (Often it is very difficult to locate leakage paths in buildings. Chemical smoke from smoke bombs can be used to find these leakage paths. The high pressure sides of smoke barriers are exposed to heavy concentrations of chemical smoke, while the low pressure side of the barrier is examined for smoke leakage that indicates the location of a leakage path. Exterior walls, interior partitions, floors and ceilings including areas above suspended ceilings must not be overlooked when hunting for excessive leakage areas.) Then the zone should be retested.

6.7 Test for smoke feedback into supply air. Place six smoke bombs (3 minute duration size) in a metal container, simultaneously ignite all bombs, and locate container near exhaust inlet in smoke zone being tested so that all of the chemical smoke produced by the bombs is drawn directly into the exhaust air stream. Check that air supplied to other zones of the building has no trace of chemical smoke. If chemical smoke is detected in this supply air, its path should be determined, the path should be blocked, and then the smoke feedback test should be conducted again. (The two most likely causes of smoke feedback are a leaky or partly opened return air damper and an outside air inlet located in the vicinity of the exhaust air outlet.)

6.8 Make sure that this zone has been returned to its normal setting before continuing to test other zones.

7. **Duct mounted smoke detector test.** Verify that the smoke detector is properly selected and properly installed to satisfactorily measure any products of combustion located in the duct. Smoke is drawn through the detector sampling chamber by the air flow velocity pressure. Since velocity pressure is a function of the volume of air flowing (cfm) and the area of the duct, the test team shall confirm that the velocity pressure is within the range specified by the equipment manufacturer and the contract specifications. Test the duct mounted smoke detector operation by setting off a smoke bomb in the air stream ahead of the detector. Confirm that the detector signals the alarm properly and that the total post-alarm sequence is proper.

## EXHIBIT C TEST PROCEDURES FOR STAIRWELL PRESSURIZATION SYSTEMS

1. **Scope.** The test procedures described in this EXHIBIT apply to systems for stairwell pressurization. These procedures should be thought of as an initial effort to develop information which could be of use to engineers and code officials tasked with determining the acceptability of a pressurized stairwell system. It is anticipated that users will want to modify the methods to suit their specific needs.

### 2. General references.

a. ASHRAE manual "Design of Smoke Control Systems for Buildings" by Klote and Fothergill consolidates and systematically presents data and calculational procedures necessary to smoke control systems designers and discusses design criteria. Included are discussions of the driving forces of smoke movement, the principles of smoke control, calculation of effective flow areas, concept of symmetry, and design parameters. A computer program for analysis of smoke control systems is presented. Concepts of stairwell pressurization and zoned smoke control are presented.

b. NFPA 92A, Recommended Practice for Smoke Control Systems, is a draft document to be voted on by NFPA in November 1987. This document provides recommendations about design, installation, testing, operation, and maintenance of new and retrofitted mechanical air conditioning and ventilation systems for the control of smoke.

3. **Emergency power.** If standby power or other emergency power has been provided for the operation of the stairwell pressurization control system, acceptance testing shall be conducted with emergency power and normal power.

4. **Normal operation test.** With all building HVAC systems in normal operation, any zoned smoke control systems shut off, and the stairwell doors closed, measure and record the pressure differences across each stairwell door. The sign convention for all pressure difference readings in the stairwell tests is: a pressure difference resulting from a flow from the stairwell is positive, and a pressure difference resulting from a flow to the stairwell is negative. Evaluate these pressure differences to determine that they are appropriate for the balanced HVAC system.

5. **Stairwell pressurization test.** Activate the stairwell pressurization systems by putting a detector in alarm as required by the contract documents. Test each pressurized stairwell by conducting the

following steps.

5.1 With all stairwell doors closed (except for the exterior ground floor door if it is required to be opened upon system activation), measure and record pressure differences across each closed stairwell door.

5.2 Open the exterior ground floor stairwell door (except if the exterior ground floor door is required to be opened upon system activation), and measure and record pressure differences across each closed stairwell door. For stairwells without a ground floor exterior door, another highly severe open door condition must be tested. This can be an exterior door not at the ground floor or a large flow path to the outside created by opening the stairwell door and other doors including an exterior building door.

5.3 Open an additional stairwell door, and measure and record pressure differences across each closed stairwell door. Repeat this step opening another door each time until the required number of doors is opened. The required number of doors is that number that must be opened during testing as stipulated in the applicable codes or contract documents.

5.4 With the required number of doors opened, check flow direction through open doorways using a 1.83 m (6 ft) strip of tissue paper secured at the top of the door frame.

5.5 Check that the measured pressure difference is within the acceptable range as defined in the contract documents. If the pressure difference is not in the acceptable range, double check that the states of fans, dampers and doors is as required. If any of these is not as required, they should be fixed and the zone retested. After this, if the pressure difference is not acceptable, the flow rate of air to the stairwell in question should be measured and adjusted as appropriate. If the pressure differences are too low after these actions, excessive air leakage paths in the construction should be filled, caulked or sealed as appropriate. (Often it is very difficult to locate leakage paths in buildings. Chemical smoke from smoke bombs can be used to find these leakage paths. The stairwell is filled with chemical smoke and pressurized, while the low pressure side of the stairwell barriers are examined for smoke leakage that indicates the location of a leakage path.) Then the zone should be retested.

# CHAPTER 8 UNITARY AIR CONDITIONING EQUIPMENT

1. **Scope.** This part provides inspection and testing procedures for unitary air conditioning equipment. A unitary air conditioning unit consists of one or more factory-made assemblies designed to be used as a matched assembly. It normally has an evaporator, a compressor, a condenser, and may include a heating section. Included equipment are packaged rooftop units, computer room air conditioning units, and packaged terminal air conditioners (PTAC) which are also known as through-the-wall units. Heat pumps are not included in this chapter.

## 2. Reference standards.

a. ASHRAE Standard 15 - Safety Code for Mechanical Refrigeration.

b. ASHRAE Standard 37 - Method of Testing for Rating Unitary Air Conditioning and Heat Pump Equipment.

c. ASHRAE Standard 41.6 - Standard Method for Measurement of Moist Air Properties.

d. ASHRAE Standard 58 - Method of Testing Room Air Conditioner Heating Capacity.

e. ASHRAE Standard 62 - Ventilation for Acceptable Indoor Air Quality.

f. ASHRAE Standard 111-1988 - Practices for Measurement, Testing, Adjusting and Balancing of Building Heating, Ventilation, Air Conditioning and Refrigeration Systems.

g. ARI Standard 110 - Standard for Air-Conditioning and Refrigerating Equipment Nameplate Voltages.

h. ARI Standard 210 - Standard for Unitary Air-Conditioning Equipment.

i. SRI Standard 310 - Standard for Packaged Terminal Air- Conditioners.

j. ARI Standard 360 - Standard for Commercial and Industrial Unitary Air-Conditioning Equipment.

k. ARI Standard 630 - Standard for Selection, Installation, and Servicing of Humidifiers.

l. Associated Air Balance Council - National Standards for Total System

Balance.

m. National Environmental Balancing Bureau - Procedural Standards for Testing-balancing-adjusting of Environmental Systems.

n. Applicable codes of the National Fire Protection Association.

o. Applicable codes of Underwriters Laboratories, Inc.

## 3. Unitary air conditioning equipment inspection.

a. Unitary air conditioning equipment shall be inspected for construction and installation to meet safety and functional requirements.

b. See EXHIBIT 8-A for inspection procedures and Appendix for inspection check lists.

## 4. Unitary air conditioning equipment testing.

4.1 Unitary air conditioning equipment shall be tested in the field to meet the capacity requirements of the contract specifications. Two basic type of tests shall be included:

4.1.1 Capacity and other performance compliance of the air conditioning unit.

4.1.2 Functional performance compliance of the automatic control of the unit.

4.2 If the building load at the time of testing does not meet the system capacity, introduction of false load may be necessary. Tests shall not cause excessively uncomfortable conditions in the building.

4.3 See EXHIBIT 8-B for test procedures and Appendix for test work sheets.

## EXHIBIT 8-A INSPECTION PROCEDURES FOR UNITARY AIR CONDITIONING UNITS

1. **Scope.** The inspection procedures described in this EXHIBIT apply to unitary air conditioning units. Included equipment are packaged rooftop units, computer room air conditioning units, and packaged terminal air conditioners (PTAC).

### 2. Industry standards.

a. ASHRAE Standard 15 (Safety Code for Mechanical Refrigeration) is intended to assure the safe design, construction, installation, operation, and inspection of refrigeration systems. Among other safety features and precautions, this Standard describes requirements of pressure-limiting devices and pressure-relief protection, including installation requirements of refrigerant piping and machinery room housing refrigerating machine.

b. ASHRAE Standard 37 (Method of Testing for Rating Unitary Air Conditioning and Heat Pump Equipment) provides standard test methods for determining the cooling capacity of unitary air-conditioning equipment and the cooling and/or heating capacities of unitary heat pump equipment. Unitary equipment is limited to electrically driven mechanical compression types. It does not include testing method for room air-conditioners.

c. ASHRAE Standard 62 (Ventilation for Acceptable Indoor Air Quality) gives ambient air quality guidelines and outdoor air requirements for most space ventilation applications. It also gives general requirements for ventilation systems and equipment.

d. ARI Standard 110 (Air-Conditioning and Refrigeration equipment Nameplate Voltages) provides definitions, classifications, recommended standard nameplate voltages, recommended maximum and minimum utilization voltages for air-conditioning and refrigerating equipment, heat pumps, and electric furnaces.

e. ARI Standard 210 (Unitary Air-Conditioning Equipment) provides definitions, classifications, requirements for testing and rating, performance requirements, safety requirements, and conformation conditions for factory-made residential, commercial, and industrial air-conditioners or matched assemblies with electrically-driven mechanical compressors. This standard apply to units with cooling capacities less than 135,000 Btuh.

f. ARI Standard 310 (Packaged Terminal Air-Conditioners) applies to factory-made residential, commercial, and industrial packaged terminal air-conditioners. It provides definitions, classifications, standard equipment, requirements for testing and rating, specifications, literature and advertising requirements, performance requirements, design, construction and assembly requirements for safety, and conformance conditions. This standard does not applies to rating and testing of individual assemblies, such as a cooling or heating section, for separate use and may be used for systems with a total external duct static resistance up to 0.1 inch of water.

g. ARI Standard 360 (Commercial and Industrial Unitary Air-Conditioning Equipment) provides, for commercial and industrial unitary air-conditioning equipment: definitions and classification; requirements for testing and rating; specifications, literature and advertising requirements; performance requirements; safety requirements; and conformance conditions. This standard does not apply to unitary air-conditioners with capacities less than 135,000 Btuh.

h. ARI Standard 630 (Standard for Selection, Installation, and Servicing of Humidifiers) describes humidifier selection procedure, installation practices, and service practices of humidifiers used in central stations and self-contained applications.

## 3. Unitary air conditioning unit general inspection.

3.1 Review equipment manufacturer's instructions on start-up and operation procedures.

3.2 Give general inspection of compressor, refrigerant system, fan, motor, air filters, cooling coils, heating coils, dampers, fan and coil bases, vibration isolation units, outdoor heat exchanger, and their associated equipment, including associated electrical equipment, piping, ductwork, etc. Be sure that no apparent damage or rusting occurred.

3.3 Check equipment name plates to verify equipment model and serial number. They must have the same model numbers as approved submittals.

3.4 Check for service access spaces around unit for operation and maintenance. Manufacturer's recommended spaces must be provided. Pay special attention to coil and filter replacement and cleaning spaces and access spaces.

3.5 Inspect equipment space for possible fire hazards. The space should be kept free of combustible material and construction debris.

3.6 Verify service piping (steam, gas, condenser water, condensate, etc.), pipe fittings and accessary equipment for the unit against project drawings and equipment manufacturer's recommendations for completeness and proper installation. Fittings and accessories include but not limited to valves, strainers, thermometer wells, piping supports, steam traps, etc.

3.7 Check water flow direction marks of check valves and flow switches.

3.8 Check piping at equipment connections. Pipes should be supported from building structure without undue stress on coils.

3.9 All moving parts (motors, belts, etc.) should have protective shields for personnel safety.

3.10 Check alignment of motor driven equipment. Using some simple tools such as straight edges, square edges, plumb lines, and strings yield good results. Also observe shaft and coupling for misalignment while equipment is running.

3.11 Observe belt tightness of fans. Use belt tension gage if needed. Belt tension should be as recommended by belt manufacturer.

3.12 Make sure required lubrication is complete (fan, motor, etc.)

3.13 Be sure the system is charged with the right kind of refrigerant. Check sight glass for proper level.

3.14 Be sure oil filter is properly installed and clean.

3.15 Be sure crankcase heater is installed snugly in position. Crankcase heater should be on during compressor off time.

3.16 Check oil level of compressor before and during compressor operation. Oil should not be foaming excessively.

3.17 Check for completeness of required instrumentation, including thermometers, gages, temperature and flow measuring and control devices. Required straight pipe runs and arrangements for temperature and flow measuring devices must be met.

3.18 Verify installed wiring against project drawings and manufacturer's submittals.

3.19 Check electric equipment and controls for proper grounding.

3.20 Check safety control wiring connections. All safety control switches (switches respond to temperature, pressure, smoke, etc. to break the safety control circuit) should be connected in the ungrounded conductor.

3.21 Check all electrical connections for tightness.

3.22 For motor starter equipped with overcurrent heaters, check heater sizes against starter manufacturer's recommendations. The recommendations are usually contained in operator's manual or posted in starter cabinet.

3.23 Test-run motors (fan, pump, etc.) to check correct direction of rotation.

3.24 Check surface paint for damages and omissions. Equipment nameplates must not be painted over. Required equipment labels must be present and legible.

3.25 Note any unusual noise and vibration.

3.26 No leakage should be noted for water, oil, and steam.

3.27 Inspect duct connections at air conditioning unit for excessive air leakage.

3.28 Be sure that temperature and pressure indicators for oil system are functioning properly to indicate the oil system operation. Oil pressure must be as recommended by the manufacturer.

3.29 Check compressor interlocking function with oil pressure to insure the operation of paragraph 3.28 above.

3.30 Be sure oil pump is wired separately from circuit feeding to the compressor if so specified.

3.31 Be sure oil filter is properly installed and clean.

3.32 Check oil heating system for proper operation. Electric wiring should be verified as per manufacturer's submittals or checked to be sure that crankcase heater power is on even when the main power is off. The crankcase heater should be installed snugly in its position. It should be on during compressor off time.

3.33 Check oil level before and during operation. Oil should not be foaming excessively.

3.34 For units with remote condensers, check refrigerant pipe pitch and oil traps for proper oil return.

3.35 For air cooled and evaporatively cooled units, spaces for air circulation is important. Be sure that manufacturer's recommendations are followed and air is not short circulated from discharge to intake.

3.36 Check direction of fan rotation for air cooled condenser.

3.27 For air cooled condensers equipped with damper controls for low ambient operation, check damper mechanism for proper adjustment and operation.

3.38 Check direction of fan rotation for evaporative condenser.

3.39 Check water level of evaporative condenser. Water float valve shall not "chatter". Spray nozzles should have correct pattern without blockage. There shall be no excessive water carry-through.

3.40 If evaporative condenser is specified and equipped with bleed-off arrangement, visually check valve adjustment for flow.

3.41 Additional inspection procedures specifically pertaining to rooftop, computer room, and packaged terminal air-conditioners are listed in paragraphs 4, 5, and 6 below.

## 4. Inspection items specific to rooftop units.

4.1 Check unit location in relationship to roof supporting structure. Unit manufacturer's instruction must be followed.

4.2 Check roof curb and unit installation for correct leveling.

4.3 Noise is often a problem for rooftop units. Inspect to make sure that the unit and ducts are properly installed. Ducts should have flexible connections and they should not be in contact with roofing structure above flexible connections. Spaces between ducts or pipes and roofing structure in duct/pipe sleeves should be sealed.

4.4 Inspection check list CL 8A-1 for rooftop air conditioning units is included in the Appendix.

## 5. Inspection items specific to computer room units.

5.1 For units equipped with indicating lights and test switches, press switches to verify indicating light status with unit operation. Indicating lights usually include power on/off, system on/off, humidifier on/off, free-cooling status, hot gas status, room or return air humidity range, cooling and heating status. Note that indicating lights usually read room conditions independent of system controls.

5.2 For units equipped with audible alarms, create unfavorable conditions to confirm alarm functions. Some units may have alarms in conjunction with indicating lights. Check that audible alarms can be manually silenced, if so specified or included in product data.

5.3 If unit is specified to dehumidify only when air flow is reduced, check fan speed control or damper control against compressor operation to verify control.

5.4 For units equipped with underfloor water detector, fire detector, and smoke detector, create conditions (presence of water, high temperature, and smoke) at the respective sensors to verify alarm actions.

5.5 Verify sensor calibrations and readouts.

5.6 Check that control deadbands and alarm set points can be easily changed if so specified.

5.7 Inspection check list CL 8A-2 for computer room air conditioning units is included in the Appendix.

## 6. Inspection items specific to packaged terminal air-conditioners.

6.1 Packaged terminal air-conditioners are installed in wall sleeves. Inspect installation to make sure that units may be removed easily for servicing and replacement.

6.2 Inspect around units to be sure that wall sleeves, unit cabinets, and wall louvers are installed properly for weatherproofing to seal out wind, rain, snow, and insects.

6.3 Condensate from cooling coil is usually rejected in the condenser air stream. Inspect units during time of high humidity (either high space humidity or high outdoor humidity) to be sure that condensate is not staining building exterior.

6.4 Turn unit controls to change outside damper positions to be sure that dampers are operating properly. Dampers should be closed tightly when units are off.

6.5 Inspection check list CL 8A-3 for packaged terminal air-conditioner is included in the Appendix.

## 7. Fan.

7.1 For large units inspect fan housing access door and pressure latches for tightness. Open and close doors to detect interference of door with thermal insulation and other equipment.

7.2 Inspect bearing for proper oil or grease application. Grease lines for bearings should extend to outside of duct connections with grease fittings. Oiling shall not require dismantling of fans, ducts, or other components if so specified in contract documents.

7.3 Inspect belt guard for access to oiling, speed counting device, and other maintenance requirements.

7.4 Observe fan steadiness during operation and excessive vibration transmission to building supporting structure.

7.5 For outlet damper or inlet vane controls inspect control linkage manually or by manipulating controller for the full range of the stroke. When a single operator controls inlet vanes of double inlet fans, inlet vanes on both inlet openings must move in unison. Inspect inlet vane rotation direction with respect to that of the fan wheel.

7.6 Fans exposed to weather should have protective weather hoods over motors and drives.

7.7 For fans without duct connections, unless they are housed in plenums, they must be provided with protective devices for personnel safety such as wire mesh or expanded metal screens at inlets and outlets.

## 8. Heating and cooling coils.

8.1 Inspect heat transfer fins for damages.

8.2 Inspect baffles between coils and casing to assure that air is not bypassing coils.

8.3 Inspect cooling coil drain pans and drain pipes. For large units with multi-coil assemblies, each coil must have individual pans with drain pipes to avoid flooding of lower coils. Cooling coil drain traps must be adequate for the static pressure imposed.

8.4 Inspect pipe fittings, valves, and coil accessories in accordance with specifications and drawings. Included are water supply, water return, steam supply, condensate return, air vents, and drains.

8.5 Inspect steam coils for possible coil freezing problem. Good condensate draining must be provided: adequate slope of tubes, adequate pressure head between coils and steam traps (minimum 18 in.), and vacuum breakers at high position of coils. Adequate sizing of steam traps should be checked if the requirements are not given in the contract specifications.

8.6 Steam main drips must be provided before coil connections.

8.7 Check temperature of steam traps and condensate piping for possible steam leaks. They must not be unduly hot.

8.8 Inspect primary element installation for flow measurement devices, if specified. The specified distance of pipe lengths and accessories (such as water straightening devices) must be viewed as minimum requirements.

## 9. Air filters.

9.1 Inspect filters for air leakage between filters and holding frames and between filter assembly and unit casing. Inspect positive sealing devices for air leakage, if specified.

9.2 For large units with automatic renewable type air filters, inspect medium advancing and override operation (pressure control, timer setting, media switch, etc. See specifications for project requirements).

9.3 Inspect filter gage sensing tips and lines for correct static pressure sensing.

9.4 For inclined manometer type filter gages check for correct installation levels.

9.5 Filter holding frames must be anchored securely to air conditioning unit casing.

9.6 Make sure adequate access spaces are provided for filter media replacement.

9.7 Filter media must be new (clean) at the time of commissioning inspection.

9.8 Check the number of spare filters provided by the contractor against contract specification requirements.

## 10. Dampers.

10.1 Verify that the blade arrangement, bearing material and edge sealing material meet the requirement of the specifications.

10.2 Inspect full range of damper movement by manipulating actuator. Verify damper closing position.

10.3 Felt strips should be provided for backdraft dampers. Dampers shall not rattle during operation.

10.4 all dampers in ducts must have access doors in accordance with specifications. Doors must be air tight.

## 11. Air louvers.

11.1 Verify material, arrangement, and dimensions.

11.2 Verify material and mesh size of bird or insect screens.

## 12. Casings.

12.1 Inspect casing for integrity.

12.2 Verify access door sizes, gasket tightness, and latch arrangement.

12.3 If required by contract documents, make sure flexible connections are installed between air conditioning equipment and duct system. Check specifications for material and construction of flexible connections. Verify that all pipings and conduits crossing the flexible connections also include a flexible connection to maintain the integration of the connections.

## 13. Thermal insulation.

13.1 Check thermal insulation for damages and omissions.

13.2 Material, thickness, and finish of thermal insulation and vapor barrier must be as specified.

13.3 Check vapor barrier downstream of cooling coil for integrity.

## 14. Controls.

14.1 Most unitary units are selected with factory installed controls to satisfy the requirements of contract specifications. The commissioning team should be familiar with the specifications and manufacturer's operating instructions to verify the control operations.

14.2 For units having pneumatic interface with building pneumatic control systems, inspect interfacing devices (usually electric to pneumatic devices or vice versa) to make sure that the correct transducing and control are achieved.

## EXHIBIT 8-B TEST PROCEDURES FOR UNITARY AIR CONDITIONING UNITS

1. **Scope.** The test procedures described in this EXHIBIT apply to unitary air conditioning units. Included equipment are packaged rooftop units, computer room air conditioning units, and packaged terminal air conditioners (PTAC).

### 2. Industry standards.

a. ASHRAE Standard 37 (Method of Testing for Rating Unitary Air Conditioning and Heat Pump Equipment) provides standard test methods for determining the cooling capacity of unitary air- conditioning equipment and the cooling and/or heating capacities of unitary heat pump equipment. Unitary equipment is limited to electrically driven mechanical compression types. It does not include testing method for room air-conditioners.

b. ASHRAE Standard 41.6 (Standard Method for Measurement of Moist Air Properties) gives recommended practices and procedures for measurement and calculations of moist air properties. It describes moisture measuring instruments, the ranges of conditions these instruments are practical, their accuracies, and the techniques of use to achieve desired accuracies. The instruments included are psychrometer, dew point hygrometer, heated electrical salt-phase transition hygrometer, Dunmore type sensor, and electrolytic hygrometer. Calibration and reference standards are also discussed.

c. ASHRAE Standard 58 (Method of Testing Room Air Conditioner Heating Capacity) prescribes test methods for determining the heating capacities and air flow quantities for room air conditioners equipped with means for room heating. It is used to test through-the-wall, window, or console air conditioners.

d. ARI Standard 210 (Unitary Air-Conditioning Equipment) provides definitions, classifications, requirements for testing and rating, performance requirements, safety requirements, and conformation conditions for factory-made residential, commercial, and industrial air-conditioners or matched assemblies with electrically-driven mechanical compressors. This standard applies to units with cooling capacities less than 135,000 Btuh.

e. ARI Standard 310 (Packaged Terminal Air-Conditioners) applies to factory-made residential, commercial, and industrial packaged terminal air-conditioners. It provides definitions, classifications, standard equipment, requirements for testing and rating, specifications, literature and advertising requirements, performance requirements, design, construction and assembly requirements for safety, and conformance conditions. This standard does not apply to rating and testing of individual assemblies, such as a cooling or heating section, for separate use and may be used for systems with a total external duct static resistance up to 24.9 Pa (0.1 inch of water).

f. ARI Standard 360 (Commercial and Industrial Unitary Air-Conditioning Equipment) provides, for commercial and industrial unitary air-conditioning equipment: definitions and classification; requirements for testing and rating; specifications, literature and advertising requirements; performance requirements; safety requirements; and conformance conditions. This standard does not apply to unitary air- conditioners with capacities less than 135,000 Btuh.

g. Associated Air Balance Council National Standards (National Standards for Total System Balance) is an industry standard for establishing a minimum set of field and balancing standards. This Standard together with the one in paragraph h. below differ from all other standards listed here in that these two standards are solely for field testing, adjusting, and balancing of HVAC systems. This Standard describes measurement instruments and their use, some basic system design information, and procedures for testing, adjusting, and balancing of air and water systems. Detailed equipment testing is not included.

h. National Environmental Balancing Bureau Standard (Procedural Standards for Testing-Balancing-adjusting of Environmental Systems) is a standard similar in purpose and practice to the previous standard for field testing, adjusting and balancing of HVAC systems.

## 3. General.

3.1 Since the capacities of unitary air conditioning units in contract specifications are for the entire assemblies and are rated by specifying the air conditioning capacities (air flow rates, states of air, heating/cooling capacities, etc.) and conditions of condensing media (water states and flow rates for water cooled condensers, states of air for air cooled condensers, etc.), verification of actual capacities under the specified conditions is the main task of testing.

3.2 Limited testing of PTAC is recommended in this guide. This is based on the following considerations:

3.2.1 Variations of equipment arrangement of PTAC is not large.

3.2.2 The contract specification usually requires that the units be certified under the ARI Unitary Air-Conditioner Certification Program.

3.2.3 Accurate measurement of air flow rate in the field without altering the unit performance is difficult for PTAC units.

3.3 One of the important measurements in rooftop and computer room air conditioning unit testing is the measurement of supply air flow rates. Depending on field duct arrangements of the project, temporary alteration of ducts to accommodate measurement instruments may be necessary. However, temporarily altering ductwork may be costly and should be done as a last resort when the system is not meeting performance. Good practices for measuring air flow should be followed (see Chapter 2 AND BASIC MEASUREMENT). However, the duct alteration should not unduly change the unit performance.

3.4 Functional inspection and test is based on the premise that the construction contractor has tested, adjusted, and balanced the entire air and water systems and is ready for normal operation. Certain preparatory procedures listed in this section are needed before commencing functional performance tests of units.

3.5 All architectural openings, such as windows and doors, should be at their normally used positions (Check both architectural and mechanical drawings).

3.6 All fans (supply, return, exhaust, transfer) which may influence the air balance in the area should be operating at their normal conditions.

3.7 All system interlocks should be at their normal operational condition.

3.8 All safety devices and provisions have been inspected and tested already.

3.9 The space temperature and humidity controls should be set at normal operating conditions.

3.10 Air flow rate measurement of fans and subsystems (if air flow rates differ from that of the main fan) should be performed before other tests.

3.11 All manual damper positions as set by the construction contractor should be marked before they are attempted to be changed for tests, so their original positions may be restored, if necessary.

3.12 It should be recognized that most installations of air systems are not at ideal conditions for flow measurements. Extraordinary caution and details should be paid to the selection of sensor locations and measurement techniques.

3.13 Fan ratings supplied by fan manufacturers and air flow rates of the design documents are generally in standard air conditions, approximately dry air at 21.1 °C (70 °F) and 101.3 kPa (29.92 in. of Hg), or 1.20 kg/m$^3$ (0.0750 lb/cu. ft) unless noted otherwise. It is generally adequate to use volumetric flow rates for commissioning purpose. If the temperature, humidity, and barometric pressure differ substantially from those of the standard air, the volumetric flow rates from the test results must be adjusted.

3.14 Check for dampers installed in main ducts that have no function in balancing air between duct branches, set the blades of these dampers parallel to the air flow, or have the dampers removed.

3.15 The preferred method of measuring air flow rate is the pitot tube traverse method. It is extremely important in selecting the location in the ducts for the pitot measurement. If packaged air flow measuring stations are specified and installed, they should be used after a preliminary check of its performance. Use SE-9 to 11 for air velocity measurement and SE-12 for volume air flow rate.

## 4. Instrumentation.

4.1 Make sure that all instrumentation is in good working order and is in calibration. See Chapter 2 AND BASIC MEASUREMENT for calibration of instruments. Instrumentation calibration work sheet WS 8B-1 is included in the Appendix.

4.2 Instruments required by the contract specification and/or installed by the contractor or equipment manufacturers may be used for performance tests, if they meet the accuracy and calibration requirements of this Section. (The glass thermometers installed on water pipes for maintenance purposes do not usually meet the requirements for performance tests.)

4.3 The required measurement, minimum accuracies, and instruments measurement precautions are given below:

4.3.1 Temperature.

4.3.1.1 Entering and leaving condenser water temperature, and entering and leaving hot water temperature of hot water humidifiers. The measurement system error shall not exceed +/- 0.1 °C (0.2 °F).

4.3.1.2 Temperature differential of entering and leaving water for the applications of paragraph 4.3.1.1 above. Direct measurement of this measurement is preferred over deducing the difference from separate temperature measurements of entering and leaving water. The measurement system error shall not exceed +/- 0.1 °C (0.2 °F).

4.3.1.3 Steam temperature of steam coils and steam humidifiers. The measurement system error shall not exceed 0.6 °C (1 °F). Locate sensing device after steam control valves.

4.3.1.4 Condensate temperature of steam coil. The measurement system error shall not exceed 0.6 °C (1 °F). Locate sensing element after traps. If coils are individually trapped, temperature sensing device should be in the combined condensate pipe.

4.1.3.5 Entering and leaving air temperature of units. The measurement error shall not exceed +/- 0.3 °C (0.5 °F). Stratification is a common phenomenon in air measurement. Since both the flow rate and temperature distribution may vary across the coils or air plenums, it is important to obtain the average temperature of the flow. At least one measurement at each one square foot of coil face area or plenum cross-sectional area shall be taken unless the measurement is for outside air or the measurement is taken in a thoroughly mixed air stream.

4.1.3.5 The temperature differential of entering and leaving air. This measurement is preferred over deducing the difference from separate temperature measurements of entering and leaving air in applications of measuring air temperature differentials. The measurement system error shall not exceed +/- 0.3 °C (0.5 °F). The precautions for measurements described in the previous paragraph must be observed.

4.1.3.6 Entering and leaving air relative humidity, wet bulb temperature, or dew point temperature for cooling coils and humidifiers. The total system measurement error shall not exceed +/- 0.6 °C (1 °F) wet bulb or equivalent. The humidity conditions before and after a coil may also be stratified. With certain instruments such as sling psychrometers it is difficult to make multiply measurements across the face of the coil. Locations away from coils should be selected for single humidity measurements.

4.3.2 Flow rate.

4.3.2.1 Water or steam flow rates for coils or humidifiers. The total error of combined sensing and readout devices shall not exceed +/- 3% of specified flow rates. The minimum pipe length requirements must be observed or flow straightener installed in accordance with the recommendations of Chapter 2, AND BASIC MEASUREMENT.

4.3.3 Pressure.

4.3.3.1 Steam pressure. The measurement system error shall not exceed +/- 689.5 Pa (0.1 psi). Steam pressure shall be measured after steam control valve.

4.3.3.2 Pressure gages installed on pipes for the purpose of maintenance operation may be used to measure the water pressure at inlet and outlet of coils if they are calibrated and meet accuracy requirements. The measurement error shall not exceed +/- 3.448 kPa (0.5 psig).

4.3.3.3 Air static pressure and total pressure measurement. The measurement system error shall not exceed +/- 12.4 Pa (0.05 in. of water).

4.4 Instrumentation calibration test work sheet for air conditioning systems, WS 8B-1, is included in the appendix.

## 5. Rooftop and computer room unit tests.

5.1 Air flow rate measurement. The total air flow rate of a system must be measured and verified to meet specifications first before all other measurements. Additionally, air distribution to individual outlets must also be measured and verified.

5.1.1 Project specification for some fans (usually for large units) are given in flow rate and static pressure pairs. The flow rates are the actually required air quantities. The pressure requirements are only estimates. After a construction project is balanced by the air balancing contractor, the system should provide the specified flow rates at the finally adjusted fan pressure. This pressure in most cases may be different from the specified rates.

5.1.2 For smaller units without external ducts for air distribution, external static pressure is not specified in the construction specification. Therefore, only air flow rates need to be measured.

5.1.3 When fans are tested and rated in the laboratories, they are tested under ideal inlet and outlet conditions as prescribed in the ASHRAE (and AMCA) standards. In overwhelming cases of actual installations, the site conditions of ducts (also called system effect factors) alter the fan performance, sometimes substantially. The fan manufacturers base their submittals on matching the performance of the laboratory (or allowed equivalent) results (fan curves or tables) with estimated air friction (the specified pressure head). Any mismatch between the laboratory performance and the actual performance is corrected by adjusting and balancing of the entire air system. Therefore, during commissioning process it is important that a) the measured fan air flow rates satisfies the specified fan air flow rates; b) all spaces receive their required air flow rates; and c) the measured fan pressure heads not necessary equal the specified fan pressure heads.

5.1.4 There is no fixed rules which can be applied universally in selection of measurement methods in determining air flow rates of fans. The persons responsible for commissioning tests must use their judgement in deciding the method or combination of methods for performing the test.

5.1.5 Using Pitot tube to traverse the main ducts of the air conditioning unit is the preferred method. Make sure the air flow at the location of measurement is steady (after the recommended minimum length of straight duct run or after straightening vanes). See EXHIBIT 2-C, STP-5 for measurement procedures.

5.1.6 For very large units, measuring air flow rates at coil face or air filter face with anemometer may be used for supply fan measurement, if good locations for pitot measurement can not be found. See EXHIBIT 2-C, STP-6 for measurement procedures.

5.1.7 Caused by possible external and internal disturbances, air flow rate, pressure, electric current rate, power consumption, and fan speed measurements shall be repeated 5 times and the results averaged to represent the fan performance.

5.1.8 Required measurement data:

5.1.8.1 Total supply air flow rate, Q, in $m^3/s$ ($ft^3/min$). This is the only air flow measurement required for units without external distributing ducts.

5.1.8.2 Depending on ductwork arrangement of the air conditioning unit (lacking inlet or outlet duct), the pressure measurement are different. Consult EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS for measurement requirements of different duct systems. The majority of installations have inlet and outlet ducts (or plenums) for fans. The following pressures, all in units of Pa (in. of water) should be measured.

* Total pressure at fan inlet duct, $P_{t(in)}$
* Total pressure at fan outlet duct, $P_{t(out)}$
* Static pressure at fan inlet duct, $P_{s(in)}$
* Static pressure at fan outlet duct, $P_{s(out)}$
* Velocity pressure at fan inlet duct, $P_{v(in)}$
* Velocity pressure at fan outlet duct, $P_{v(out)}$
* Barometric pressure.

5.1.8.3 Voltage of electrical service, V

5.1.8.4 Electric current, A

5.1.8.5 Rotating speed of fan, rpm

5.1.9 It is the responsibility of the construction contractor to supply a fan to meet the construction specifications and to adjust and balance the entire air system. The entire air system must operate stably. During commissioning testing the commissioning team should make sure that the system stability is achieved by measuring the fan speed. Use a tachometer or stroboscope (see EXHIBIT 2-A COMMONLY USED FIELD TEST INSTRUMENTS) to measure the fan speed continuously for at least 3 minutes. The speed variation shall not exceed 3%.

5.1.10 Test procedures for constant air volume systems.

5.1.10.1 Set the outside air damper at the minimum position and the return air and relief air dampers at their appropriate positions. Disable damper automatic controls during test.

5.1.10.2 Perform the required measurements listed in 5.1.8 above.

5.1.10.3 Check air flow rates to individual spaces. Select air outlets randomly throughout the entire duct system from the same air conditioning unit. If 10% of the outlets checked is off for more than 10% of the specified flow rates, a second set of 10% outlets shall be checked. The entire air distribution system, including fans and all dampers, must be rebalanced and testing repeated, if (i) any 10% of the outlets checked have flow rates off +/- 15% from the specified flow rates; or (ii) the total of all measured flow rates of these outlets is off +/- 10% from the total of the design flow rates of the same outlets.

5.1.10.4 Set the outside air to 100% and other dampers (return and relief dampers) to their appropriate positions.

5.1.10.5 Measure electric current rate. The motor current rate must not be greater than the full load current shown on the motor mane plate.

5.1.10.6 Restore all damper controls.

5.1.11 Test procedures for variable air volume systems.

5.1.11.1 It is difficult, if not impossible, to know when the system block loads occur. Fans of variable air systems can only be tested to verify their capacities and energy rates in accordance to the specified values despite that the pressure requirements are only estimated.

5.1.11.2 Set the outside air damper at 100% position and the return air and relief air dampers at their appropriate positions. Disable damper automatic controls during test.

5.1.11.3 Manipulate duct pressure sensors by applying simulated pressure changes (thus change the fan curves on a volume-pressure diagram) and manipulate the air volume controls of the first few air outlets (thus change the system curves of the volume-pressure diagram). The contract specified fan duty point (volume flow rate and pressure) may be obtained during test. Repeated adjustment and measurement may be needed.

5.1.11.4 Perform the required measurements listed in 5.1.8 above.

5.1.11.5 The electric current rate of the motor shall not be higher than the name plate full load current.

5.1.11.6 Use similar procedures test variable air volume return air fans.

5.1.11.7 Restore all damper controls.

5.1.11.8 Randomly select a minimum of 10% of VAV units which are supplied from the same air conditioning system. Measure the maximum and the minimum supply air flow rates of these units by manipulating their respective thermostats. If 10% of the selected units having their flow rates (maximum and minimum) differ more than 10% of the specified flow rates, a second set of 10% units should be selected and measured. The entire air system must be rebalanced and testing repeated, if (i) any 10% of the units measured have flow rates off +/- 15% from the specified flow rates; or (ii) the total of all measured flow rates of the selected VAV units differs over +/- 10% from the total of the design flow rates of the same units.

5.1.11.9 During the maximum and the minimum air flow rate manipulation, verify the operation sequence of reheat coils (for units with reheat coils), recirculating fans (for units with recirculating fans), and other operational controls as required in the contract specifications.

5.1.11.10 Measure and verify the required duct static pressure at the locations of each fan static pressure sensor.

5.1.11.11 Measure static pressure of at least 25% of all branch ducts just before the last VAV unit of the branch to verify that the pressure is within + 49.8 Pa (0.2" of water) of the specified minimum pressure of the VAV units. If the static pressure is lower than the minimum pressure required or more than the total of minimum pressure plus 49.8 Pa (0.2" of water), the fan static pressure controller setting must be adjusted and duct pressure retested. The selection the these 25% branches should be estimated and judged by the Team that these branches may encounter extreme (high or low) pressure during building load changes.

5.2 Cooling/heating measurement.

5.2.1 Cooling/heating measurements should be performed after fan measurements.

5.2.2 Depending on the weather at the time of testing, false cooling or heating loads may be needed to achieve the contract specified entering air conditions to the unit. If false loads are not available at the time of commissioning, the heating and cooling tests must be postponed till the specified conditions may be maintained.

5.2.3 For cooling tests turn automatic controls to cooling. Make sure the heating coils are locked out.

5.2.4 In addition to load conditions described in paragraph 5.2.2 above, the performance of cooling depends on the conditions of the condensing media.

5.2.4.1 For air cooled units measure outside air dry bulb temperature. If the temperature is not within 1.1 °C (2 °F) of the contract specified temperature the test shall be postponed unless the temperature is within 5.6 °C (10 °F) of the contract specified temperature AND manufacturer's capacity versus ambient temperature data are available for extrapolation.

5.2.4.2 For water cooled units measure the condenser entering water temperature. Adjust flow balancing devices or other means, if necessary, to within 0.6 °C (1 °F) of the contract specified entering water temperature. This temperature shall be maintained during the test.

5.2.4.3 For water cooled units measure the condenser water flow rate. Adjust flow balancing devices or other means if necessary, to within 3% of the contract specified flow rate. This flow rate shall be maintained during the test.

5.2.5 In order to maintain steady state conditions, the cooling control must be energized during the cooling capacity test.

5.2.6 Measure cooling coil entering air dry bulb temperature. Temperature control of the air upstream of the coils may need to be adjusted or false load varied to maintain this temperature within 0.6 °C (1 °F) of the contract specified entering air dry bulb temperature. The adjustment of upstream air temperature may need be performed in conjunction with adjustment of upstream air humidity (see the following) paragraph.

5.2.7 Measure the coil entering air humidity (relative humidity, wet bulb temperature, of dew point temperature). Usually humidity needs to be added in the air by manipulating humidifier or false humidity load source. The humidity must be maintained within 5% RH or equivalent of the contract specified value.

5.2.8 Run air conditioning units for at least 20 minutes to prove that the systems are under steady state conditions. Steady state condition is achieved when three consecutive measurements of coil leaving air temperature, at 10 minute intervals, do not differ more than 0.6 °C (1 °F).

5.2.9 Measure barometric pressure.

5.2.10 Measure condenser leaving water temperature for water cooled units.

5.2.11 Measure condenser water pressure at condenser inlet and outlet for water cooled units having specified condenser water pressure drops larger than 29.86 kPa (10 ft of water).

5.2.12 Take three sets of coil air data at 5 minute intervals:

5.2.12.1 Entering air dry bulb temperature.

5.2.12.2 Leaving air dry bulb temperature.

5.2.12.3 Entering air relative humidity, wet bulb temperature, or dew point temperature.

5.2.12.4 Leaving air, relative humidity, wet bulb temperature, or dew point.

5.2.13 During heating capacity tests, make sure the cooling operation of the units are locked out and the heating operation is on.

5.2.13.1 Measure water flow rate of water heated units. Adjust balancing devices, if necessary, to within 3% of the contract specified flow rate. This water flow rate shall be maintained during the test.

5.2.13.2 Measure entering water temperature of water coil. Adjust, if necessary, to within 0.6 °C (1 °F) from the contract specified temperature. This temperature shall be maintained during the test.

5.2.13.3 Measure steam pressure and temperature for steam heated units. Check pressure and temperature against steam table to make sure that steam is at least saturated and that the steam pressure after control valve is at the specified pressure of the coil. If the indicated pressure is more than +/- 6.89 kPa (1 psi) from that specified, the steam line pressure controlling device must be adjusted. If the steam is less than saturated, it must be brought to saturation conditions before test is continued. The pressure and temperature of the steam shall be maintained during the test.

5.2.13.4 Measure steam flow rate to the coils. Adjust manual or automatic valve, if necessary, to within 3% of the contract specified flow rate. This flow rate shall be maintained during the test.

5.2.13.5 For electrically heated units, make sure electric coil controls are energized.

5.2.13.6 For gas heated units, make sure gas heaters are in operation.

5.2.13.7 Measure entering air dry bulb temperature. Temperature controls of the air entering the units may need to be adjusted or false load varied to maintain this temperature within 0.6 °C (1 °F) of the contract specified entering air dry bulb temperature.

5.2.13.8 Run the air conditioning units for at least 10 minutes to prove that the units are under steady state conditions. Steady state condition is achieved when three consecutive measurements of coil leaving air temperature, at 5 minute intervals, do not differ more than 0.6 °C (1 °F).

5.2.13.9 Take three sets of air data at 5 minute intervals:

* Entering air dry bulb temperature.

* Leaving air dry bulb temperature.

5.3 Humidifying capacity measurement.

5.3.1 This section concerns mostly with humidifiers for computer room unitary air conditioning units. In most applications water vapor is directly injected into the conditioned air stream. Therefore, the test is to measure the moisture adding capacity by measuring the inlet and outlet conditions of the air stream. It is similar to testing of unit cooling capacities. Depending on the conditions of the moisture being added to the air, a very small amount of heat energy of the water vapor may be giving to the air stream as sensible heat.

5.3.2 Humidifiers should be tested after fan and cooling/heating tests. All heating and cooling sources to the units must be turned off except for the energy to operate the fans and humidifiers.

5.3.3 The test may be performed at any entering air temperature. The commissioning team should be sure that the air leaving the humidifier section do not reach 80% RH or cause damage to buildings and equipment.

5.3.4 Test procedures.

5.3.4.1 For humidifiers injecting steam directly into the air stream, measure steam pressure and temperature at steam supply pipe. Check steam tables to make sure that steam is at least saturated and that the steam pressure is at the specified pressure. If the indicated pressure is more than +/- 6.89 kPa (1 psi) from that specified, the steam line pressure controlling device must be adjusted. Correct the degree of steam saturation, if the steam is less than saturated, before proceeding testing. The steam pressure shall be maintained during the test. For other types of humidifiers, follow equipment supplier's instructions to prepare the humidifiers for testing.

5.3.4.2 Make sure all energy sources to the unit, except for fan, control, and humidifier operation, are turned off.

5.3.4.3 Adjust humidifier controls to full capacities. Maintain full capacity during the test.

5.3.4.4 Let system run for at least 5 minutes.

5.3.4.5 Take three sets of air data at 5 minute intervals:

* Entering air dry bulb temperature.

* Leaving air dry bulb temperature.

* Entering air relative humidity, wet bulb temperature, or dew point temperature.

* Leaving air, relative humidity, wet bulb temperature, or dew point.

5.3.4.6 Observe the humidifier operation. There should not be "spitting" of water into the air stream.

5.3.5 Test work sheet for humidifier is included in test work sheets for air conditioning system component tests, WS 5B-2, in the appendix.

5.4 Air filter.

5.4.1 It is not feasible to test air filter efficiencies and dust holding capacities in the field. They must be tested in the laboratories in according with industry standards. See construction specifications.

5.4.2 For operational testing of air filters see EXHIBIT 5-A, INSPECTION PROCEDURES FOR AIR CONDITIONING SYSTEMS.

5.5 Test work sheet WS 8B-2 included in the Appendix may be used for rooftop and computer room units.

## 6. PTAC tests.

6.1 Test procedures described in this guide for PTAC are basically for operational tests.

6.2 If the contract specification requires that the units be certified under the ARI PTAC Certification Program, make sure the certification symbols are displayed on the units.

6.3 Test procedures.

6.3.1 Turn unit control to system-on position. Unit fan should be on.

6.3.2 Turn unit ventilation air control to off position.

6.3.3 Turn unit control to cooling position or set unit thermostat 10 F below space temperature.

6.3.4 Measure unit discharge air after unit is in cooling position for at least 5 minutes. This air should be below 15.6 °C (60 °F). The cooling coil should show condensation if the space dew point is over 10 °C (50 °F).

6.3.5 Turn unit control to heating position or set unit thermostat 5.6 °C (10 °F) above space temperature. If hydronic heating system is used for the system, make sure the specified hot water temperature is available.

6.3.6 Measure unit discharge air after unit is in heating position for at least 5 minutes. This air should be above 48.9 °C (120 °F).

6.3.7 Turn unit control to ventilation position. The outside air damper should be open.

6.4 Test work sheet WS 8B-3 included in the Appendix may be used for PTAC units.

## 7. Calculation and evaluation of performance.

7.1 Air flow.

7.1.1 The measured total air flow rate of the unit must not be less than the specified fan air flow rate. The motor current rate must not be greater than the full load current shown on the motor mane plate.

7.1.2 Calculate the fan total pressure or fan static pressure from pressure measurements, if pressure rating is specified in the contract documents. For the reasons stated in paragraphs 5.1 above, this pressure should be used for reference only, if the other data show that the fan performance is satisfied.

7.1.3 Air flow rates in construction documents and manufacturer's literature are usually given in standard air conditions. Designers usually do not adjust air properties for HVAC applications below 79.50 kPa (2000 ft) altitude. Therefore it does not justify to adjust measured data for ordinary heating and cooling application below this altitude. For applications above 2000 ft, the commissioning team should be careful in determining the basis of air flow rates as required in the construction documents. The Team should make sure that the measured data and the required rating are on the same bases. For adjusting of air properties at higher altitudes, see EXHIBIT 2-B STANDARD EQUATIONS FOR CALCULATIONS.

7.2 Heating and cooling capacities.

7.2.1 For heating capacities, the entering and the leaving air humidity are not required to be measured in this guide. The errors of the enthalpies of air caused by this simplification are not significant if a 50% RH entering air humidity is assumed. This assumption is justified for the majority of HVAC applications.

7.2.2 The construction documents should state the basis of unit capacity. If the basis of air flow rates are not stated, assume they are for standard air.

7.2.3 Calculation procedure.

7.2.3.1 Calculate the average entering and the average leaving air dry bulb temperature from measured data.

7.2.3.2 Calculate the average entering and the average leaving air relative humidity, wet bulb temperature, or dew point temperature from measured data. For heating capacities, only entering air calculations are needed.

7.2.3.3 Calculate the saturated water pressure of the entering air, $(P_{sw})_{ent}$, Pa (in. of Hg), knowing the entering air dry bulb temperature, using SE-1.

7.2.3.4 Calculate the entering air vapor pressure, $(P_w)_{ent}$, Pa (in. of Hg), knowing the measured humidity of entering air for cooling coil or the assumed humidity (50% RH) of the heating coil, using SE-2.

7.2.3.5 Calculate humidity ratio of entering air, $(W)_{ent}$, kg (lb) of vapor/kg (lb) of dry air, using SE-3.

7.2.3.6 Calculate enthalpy of entering air, $(H)_{ent}$, J/kg

(Btu/lb) of air, using SE-4.

7.2.3.7 Calculate enthalpy of leaving air, $(H)_{lvg}$, J/kg (Btu/lb) of air, using SE-4. For cooling coil both the dry bulb temperature and humidity are as measured. For heating coil assume the leaving air has the same humidity ratio as the entering air (calculated in step 7.2.3.5 above).

7.2.3.8 Calculate specific volume of air, v (in cu ft/lb of air), using SE-5. The air temperature at the flow measurement location must be used in this calculation.

7.2.3.9 Calculate mass flow rate of air, M, kg/s (lb/min), using SE-15. The measured volume air flow rate, Q, $m^3/s$ ($ft^3/min$), is needed in the calculation.

7.2.3.10 Calculate heating or cooling capacity of coil.

$$\text{Capacity, J/s} = M\ [(H)_{lvg} - (H)_{ent}] \qquad \text{(For SI)}$$

$$\text{Capacity, Btu/h} = 60\ M\ [(H)_{lvg} - (H)_{ent}] \qquad \text{(For Customary)}$$

7.2.3.11 Calculate net air friction across coils for coils having specified friction greater than 124.4 Pa (0.5 in. of water).

7.2.4 The tested unit capacity shall not be less than 95% of the contract specified capacity.

7.2.5 The test air friction of coil shall not be greater than 110% of the contract specified air friction.

7.3 Humidifying capacities.

7.3.1 Calculate the average entering air and the average leaving air dry bulb temperature from measured data.

7.3.2 Calculate the average relative humidity, wet bulb temperature, or dew point temperature of the entering and the leaving air from measured data.

7.3.3 Calculate the saturated water pressure of the entering air, $(P_{sw})_{ent}$, Pa (in. of Hg), knowing the entering air dry bulb temperature, using SE-1.

7.3.4 Calculate the entering air vapor pressure, $(P_w)_{ent}$, Pa (in. of Hg), knowing the measured humidity, using SE-2.

7.3.5 Calculate humidity ratio of entering air, $(W)_{ent}$, kg (lb) of vapor/kg (lb) of dry air, using SE-3.

7.3.6 Calculate the saturated water pressure of the leaving air, $(P_{sw})_{lvg}$, Pa (in. of Hg), knowing the leaving air dry bulb temperature, using SE-1.

7.3.7 Calculate the leaving air vapor pressure, $(P_w)_{lvg}$, Pa (in. of Hg), knowing the measured humidity, using SE-2.

7.3.8 Calculate humidity ratio of leaving air, $(W)_{lvg}$, kg (lb) of vapor/kg (lb) of dry air, using SE-3.

7.3.9 Calculate specific volume of air, v, $m^3$/kg ($ft^3$/lb), using SE-5. The air temperature at the flow measurement location must be used in this calculation.

7.3.10 Calculate mass flow rate of air, M, kg/s (lb/min), using SE-15. The measured volume air flow rate, Q, $m^3$/s ($ft^3$/min), is needed in the calculation.

7.3.11 Calculate humidifier capacity.

Capacity, kg/s = $M\ [(W)_{lvg} - (W)_{ent}]$ (For SI)

Capacity, (lb/h) = $60\ M\ [(W)_{lvg} - (W)_{ent}]$ (For Customary)

7.3.12 The above calculated humidifier capacity shall not be less than 95% of the contract specified capacity.

7.3.13 The humidifier shall not "spitting".

8. **Air conditioning system operational tests.** The control systems of unitary air conditioning units are factory designed and equipped. Depending on their applications and sizes, control strategies of these units are usually not as complicated as some other field erected systems. Refer to Chapter 5 test procedures (EXHIBIT 5-B TEST PROCEDURES FOR AIR CONDITIONING SYSTEMS) for operational tests for systems specified with those controls, such as economy cycles, warm-up cycles, etc.

# APPENDIX

(Inspection Check Lists and Test Work Sheets)

## INSPECTION CHECK LIST/TEST WORK SHEET

Page

## 2.1 TEST WORK SHEET WS 2C-1 -- AIR FLOW RATE IN ROUND DUCTS

Air handling system no._____ Date__________
Duct designation no.________ Test agent_______________________
Size _______________________
Specified flow rate*_____cfm Commissioning team_______________
Duct location_______________ _______________

Notes for using form:
"*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

No. Steps

Velocity pressure readings: Velocity:

Horizontal diameter:

| | | |
|---|---|---|
| Ring 1 | _____ "w.c. | _____ fpm |
| Ring 2 | _____ "w.c. | _____ fpm |
| Ring 3 | _____ "w.c. | _____ fpm |
| Ring 4 | _____ "w.c. | _____ fpm |
| Ring 5 | _____ "w.c. | _____ fpm |
| Ring 5 | _____ "w.c. | _____ fpm |
| Ring 4 | _____ "w.c. | _____ fpm |
| Ring 3 | _____ "w.c. | _____ fpm |
| Ring 2 | _____ "w.c. | _____ fpm |
| Ring 1 | _____ "w.c. | _____ fpm |

Vertical diameter:

| | | |
|---|---|---|
| Ring 1 | _____ "w.c. | _____ fpm |
| Ring 2 | _____ "w.c. | _____ fpm |
| Ring 3 | _____ "w.c. | _____ fpm |
| Ring 4 | _____ "w.c. | _____ fpm |
| Ring 5 | _____ "w.c. | _____ fpm |
| Ring 5 | _____ "w.c. | _____ fpm |
| Ring 4 | _____ "w.c. | _____ fpm |
| Ring 3 | _____ "w.c. | _____ fpm |
| Ring 2 | _____ "w.c. | _____ fpm |
| Ring 1 | _____ "w.c. | _____ fpm |

Average velocity ________ fpm

$$\text{Air flow rate} = \text{average velocity} \times \frac{\pi}{4} \times (\text{dia. of duct})^2$$

$$\%\ \text{Error} = \left(1 - \frac{\text{measured air flow rate}}{\text{specified air flow rate}}\right) \times 100\%$$

COMMENTS:__________________________________________________
__________________________________________________________

## 2.2 TEST WORK SHEET WS 2C-2 -- AIR FLOW RATE IN RECTANGLE DUCTS

Page 1

Air handling system no._____ Date__________
Duct designation no.________ Test agent________________________
Size _______________________
Specified flow rate*_____cfm Commissioning team_______________
Duct location_______________ _______________

Notes for using form:

1. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.
2. Add rows/columns and positions as necessary.

---

No. Steps

---

Velocity pressure readings: Velocity:

First row or column:

Position 1 _____ "w.c. _____ fpm
Position 2 _____ "w.c. _____ fpm
Position 3 _____ "w.c. _____ fpm
Position 4 _____ "w.c. _____ fpm
Position 5 _____ "w.c. _____ fpm
Position 6 _____ "w.c. _____ fpm
Position 7 _____ "w.c. _____ fpm

Second row or column:

Position 1 _____ "w.c. _____ fpm
Position 2 _____ "w.c. _____ fpm
Position 3 _____ "w.c. _____ fpm
Position 4 _____ "w.c. _____ fpm
Position 5 _____ "w.c. _____ fpm
Position 6 _____ "w.c. _____ fpm
Position 7 _____ "w.c. _____ fpm

Third row or column:

Position 1 _____ "w.c. _____ fpm
Position 2 _____ "w.c. _____ fpm
Position 3 _____ "w.c. _____ fpm
Position 4 _____ "w.c. _____ fpm
Position 5 _____ "w.c. _____ fpm
Position 6 _____ "w.c. _____ fpm
Position 7 _____ "w.c. _____ fpm

COMMENTS:__________________________________________________
__________________________________________________________
__________________________________________________________

TEST WORK SHEET WS 2C-2 -- AIR FLOW RATE IN RECTANGLE DUCTS (continued)
Page 2

Air handling system no._____ Date__________
Duct designation no.________ Test agent______________________
Size ______________________
Specified flow rate*_____cfm Commissioning team_______________
Duct location_______________ _______________

| No. | Steps | | | |
|---|---|---|---|---|
| | Fourth row or column: | | | |
| | Position 1 | _____ "w.c. | _____ | fpm |
| | Position 2 | _____ "w.c. | _____ | fpm |
| | Position 3 | _____ "w.c. | _____ | fpm |
| | Position 4 | _____ "w.c. | _____ | fpm |
| | Position 5 | _____ "w.c. | _____ | fpm |
| | Position 6 | _____ "w.c. | _____ | fpm |
| | Position 7 | _____ "w.c. | _____ | fpm |
| | Fifth row or column: | | | |
| | Position 1 | _____ "w.c. | _____ | fpm |
| | Position 2 | _____ "w.c. | _____ | fpm |
| | Position 3 | _____ "w.c. | _____ | fpm |
| | Position 4 | _____ "w.c. | _____ | fpm |
| | Position 5 | _____ "w.c. | _____ | fpm |
| | Position 6 | _____ "w.c. | _____ | fpm |
| | Position 7 | _____ "w.c. | _____ | fpm |
| | Sixth row or column: | | | |
| | Position 1 | _____ "w.c. | _____ | fpm |
| | Position 2 | _____ "w.c. | _____ | fpm |
| | Position 3 | _____ "w.c. | _____ | fpm |
| | Position 4 | _____ "w.c. | _____ | fpm |
| | Position 5 | _____ "w.c. | _____ | fpm |
| | Position 6 | _____ "w.c. | _____ | fpm |
| | Position 7 | _____ "w.c. | _____ | fpm |

Average velocity ________ fpm

Air flow rate = average velocity x Duct width x duct depth

$$\% \text{ Error} = \left(1 - \frac{\text{measured air flow rate}}{\text{specified air flow rate}}\right) \times 100\%$$

COMMENTS:____________________________________________________________
________________________________________________________________________

## 3.1 INSPECTION CHECK LIST CL 3A-1 -- CHILLER

Page 1

Chiller no.________________ Date__________
Make & model________________ Inspection agent________________
Serial no.________________ Commissioning team________________
Chiller type________________ ________________
Refrigerant________________ ________________
Condensing: Water____ Air____ Evap____

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| For all chillers: | | | | | | |
| 1 | Operation and maintenance manuals complete | | | | | 1 |
| 2 | Video taping of O & M performed and accepted by vendors | | | | | 2 |
| 3 | General appearances, no apparent damage | | | | | 3 |
| 4 | Headroom around chiller adequate | | | | | 4 |
| 5 | Tube pulling space adequate | | | | | 5 |
| 6 | Other access space adequate | | | | | 6 |
| 7 | Proper vibration unit installation | | | | | 7 |
| 8 | Isolation valves and balancing valves installed (unions, flanges) | | | | | 8 |
| 9 | Pipe fittings and accessories complete | | | | | 9 |
| 10 | Pipes not supported on chiller | | | | | 10 |
| 11 | Evaporator air vent provided | | | | | 11 |
| 12 | Water cooled condenser air vent provided | | | | | 12 |
| 13 | Evaporator drain extended to floor drain | | | | | 13 |
| 14 | Water cooled condenser drain extended to floor drain | | | | | 14 |
| 15 | Refrigerant relief pipe extended to outside | | | | | 15 |
| 16 | Protection shields for motor and belts | | | | | 16 |
| 17 | Alignment of motor driven components | | | | | 17 |
| 18 | Belt tightness | | | | | 18 |
| 19 | Thermometers complete | | | | | 19 |
| 20 | Pressure gages complete | | | | | 20 |
| 21 | Flow meters meet installation requirements | | | | | 21 |
| 22 | Proper refrigerant type | | | | | 22 |
| 23 | Proper refrigerant level | | | | | 23 |
| 24 | No refrigernat leakage | | | | | 24 |
| 25 | Proper oil types | | | | | 25 |

COMMENTS:________________________________________________
__________________________________________________________
__________________________________________________________

INSPECTION CHECK LIST CL 3A-1 -- CHILLER (continued)

Page 2

Chiller no.________________ Date__________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| 26 | Proper oil level | | | | | 26 |
| 27 | Piping type and flow direction labeled on piping | | | | | 27 |
| 28 | Equipment labels affixed | | | | | 28 |
| 29 | Thermal insulation complete and no damage | | | | | 29 |
| 30 | Surface paint complete | | | | | 30 |
| 31 | Control wiring installed properly | | | | | 31 |
| 32 | Power wiring installed properly | | | | | 32 |
| 33 | All elec components grounded properly | | | | | 33 |
| 34 | Oil heater installed properly | | | | | 34 |
| 35 | Size of overcurrent heater in motor starter | | | | | 35 |
| 36 | Oil filter clean | | | | | 36 |
| 37 | No unusual noise & vibration when running | | | | | 37 |

For centrifugal chillers only:

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Check alignment for field assembled unit | | | | | 1 |
| 2 | Oil system temperature and pressure gages complete | | | | | 2 |
| 3 | Compressor interlocking with oil pressure | | | | | 3 |
| 4 | Forced oil pump wired separatly | | | | | 4 |
| 5 | Adequate oil pressure when compressure shaft is turning (incl. coastdown) | | | | | 5 |
| 6 | Oil cooling system piping system complete | | | | | 6 |
| 7 | Prerotation vane closed before comressor reaches full speed | | | | | 7 |
| 8 | Prerotation vane steady when load changes | | | | | 8 |

COMMENTS:______________________________________________

______________________________________________

______________________________________________

INSPECTION CHECK LIST CL 3A-1 -- CHILLER (continued)



Chiller no.________________ Date__________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| | **For reciprocating chillers only:** | | | | | |
| 1 | Oil pump wired separately from compressor | | | | | 1 |
| 2 | Interlocking between oil pressure and compressure | | | | | 2 |
| 3 | Crankcase heater installed properly | | | | | 3 |
| 4 | Crankcase heater is on when compressor power is off | | | | | 4 |
| 5 | Crankcase heater is off when compressor is on | | | | | 5 |
| 6 | Oil has correct level before operation | | | | | 6 |
| 7 | Oil has correct level during operation | | | | | 7 |
| 8 | Oil not foaming excessively | | | | | 8 |
| 9 | For unit with remote condenser, check pitch of refrigerant pipes and oil trap | | | | | 9 |
| 10 | For unit with air cooled condenser: | | | | | |
| 10a | Adequate space for air circulation, no short circulation | | | | | 10a |
| 10b | Rotation direction of fan | | | | | 10b |
| 10c | Air damper linkage adjustment | | | | | 10c |
| 11 | For unit with evaporative condenser: | | | | | |
| 11a | Adequate space for air circulation, no short circulation | | | | | 11a |
| 11b | Rotation direction of fan | | | | | 11b |
| 11c | Water level correct | | | | | 11c |
| 11d | Float valve | | | | | 11d |
| 11e | Spray nozzle pattern | | | | | 11e |
| 11f | bleed valve adjustment | | | | | 11f |
| | **For absorption chiller only:** | | | | | |
| 1 | Automatic control line pressure (pneumatically controlled unit only) | | | | | 1 |
| 2 | Steam control valve adjusted | | | | | 2 |
| 3 | Water control valve adjusted | | | | | 3 |
| 4 | Check solution pump strainer | | | | | 4 |
| 5 | Check refrigerant pump strainer | | | | | 5 |

COMMENTS:______________________________________________

________________________________________________________

________________________________________________________

INSPECTION CHECK LIST CL 3A-1 -- CHILLER (continued)

Page 4

Chiller no.________________ Date__________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| 6 | Check Steam or hot water pipe strainer | | | | | 6 |
| 7 | Check correct installation of steam trap | | | | | 7 |
| 8 | Obtain operating data from contractor to decide if tube cleaning is necessary | | | | | 8 |
| 9 | Obtain charge data (lithium bromide and additives) | | | | | 9 |
| 10 | Draw strong and week solution samples for concentration analysis | | | | | 10 |
| 11 | Isolation valve for steam condensate | | | | | 11 |
| 12 | Isolation valve for hot water supply and return lines | | | | | 12 |
| 13 | Pressure gages and thermometers | | | | | |
| | 13a Hot water supply | | | | | 13a |
| | 13b Hot water return | | | | | 13b |
| | 13c Steam pressure gage | | | | | 13c |

For automatic tube cleaning system (ATCS) only:

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| 1 | Condenser water pump off: | | | | | |
| | 1a General appearance of ATCS, no apparent damage | | | | | 1a |
| | 1b Verify manual override (test one cycle) | | | | | 1b |
| | 1c Check diverter actuator speed setting | | | | | 1c |
| | 1d Verify indicating lights: * Power on * Diverter position * Malfunctioning | | | | | 1d |
| | 1e Verify cycle counter | | | | | 1e |
| | 1f Verify no interference with condenser flow switch | | | | | 1f |
| | 1g Check cycle timer settings | | | | | 1g |
| | 1h Check diverting valve lubrication | | | | | 1h |
| 2 | Condenser water pump on: | | | | | |
| | 2a Manually initiate cleaning action | | | | | 2a |
| | 2b Initiate cleaning action by resetting timer | | | | | 2b |

COMMENTS:______________________________________________________________

## 3.2 INSPECTION CHECK LIST CL 3B-1 -- HEAT REJECTION EQUIPMENT (COOLING TOWER, EVAPORATIVE CONDENSER, AND AIR COOLED CONDENSER)

Page 1

Equipment no.______________ Date__________
Make & model______________ Inspection agent________________

Serial no.________________ Commissioning team_______________
Type: cooling tower_________ _______________
Evap condenser________ _______________
Dry condenser_________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| General: | | | | | | |
| 1 | Operation and maintenance manuals complete | | | | | 1 |
| 2 | General appearances, no apparent damage | | | | | 2 |
| 3 | Air circulation space adequate | | | | | 3 |
| 4 | Equipment access space adequate | | | | | 4 |
| 5 | Proper vibration unit installation | | | | | 5 |
| 6 | No unusual noise & vibration when running | | | | | 6 |
| 7 | Pipe fittings, valves and accessories complete | | | | | 7 |
| 8 | Isolation valves installed | | | | | 8 |
| 9 | Balancing valves installed | | | | | 9 |
| 10 | Pipes supported on building structure member | | | | | 10 |
| 11 | Correct flow control device installation (check valve, control valve, flow meter) | | | | | 11 |
| 12 | Thermometers and wells complete | | | | | 12 |
| 13 | Pressure gages complete | | | | | 13 |
| 14 | Flow meters meet installation requirements | | | | | 14 |
| 15 | Strainers or screens as specified | | | | | 15 |
| 16 | Protection shields for motor and belts | | | | | 16 |
| 17 | Alignment of motor driven components | | | | | 17 |
| 18 | Belt tightness | | | | | 18 |
| 19 | Lubrication properly applied (motor and fan bearings, gear train) | | | | | 19 |
| 20 | Lubrication material as required | | | | | 20 |

COMMENTS:________________________________________________
________________________________________________________
________________________________________________________

INSPECTION CHECK LIST CL 3B-1 -- HEAT REJECTION EQUIPMENT (COOLING TOWER, EVAPORATIVE CONDENSER, AND AIR COOLED CONDENSER) - continued Page 2

Equipment no.______________ Date__________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| 21 | Thermal insulation complete and no damage | | | | | 21 |
| 22 | Surface paint complete | | | | | 22 |
| 23 | Piping type and flow direction labeled on piping | | | | | 23 |
| 24 | Electic wiring installed properly | | | | | 24 |
| 25 | All elec components grounded properly | | | | | 25 |
| 26 | Size of overcurrent heater in motor starter | | | | | 26 |
| 27 | Direction of fan rotation | | | | | 27 |
| | Cooling tower and evaporative condenser: | | | | | |
| 28 | Water basin cleanliness | | | | | 28 |
| 29 | Drain terminated as specified | | | | | 29 |
| 30 | No excessive water carryover in air | | | | | 30 |
| 31 | Water level in basin correct | | | | | 31 |
| 32 | Proper float operation | | | | | 32 |
| 33 | Bleed valve adjusted corretly | | | | | 33 |
| 34 | No blockage to distribution orifices | | | | | 34 |
| 35 | Correct spray nozzle pattern | | | | | 35 |
| 36 | Correct balancing between cells | | | | | 36 |
| 37 | Correct balancing between towers | | | | | 37 |
| 38 | Correct balancing between condensers | | | | | 38 |
| 39 | Winterizing as specified | | | | | 39 |
| 40 | Railing, gratings, ladder adequate and secure | | | | | 40 |
| 41 | Material and installation as required for field assembled towers | | | | | 41 |
| 42 | Tile support as required for tile filled towers | | | | | 42 |
| | Air cooled and evaporatively cooled condensers: | | | | | |
| 43 | Air damper mechanism operation . | | | | | 43 |

COMMENTS:________________________________________
________________________________________
________________________________________

## 3.3 TEST WORK SHEET WS 3C-1 -- INSTRUMENT CALIBRATION FOR COOLING PLANT

Page 1

Date__________
Test agent________________________
Commissioning team________________
________________
________________

Notes for using form:

1. This work sheet is generally used for calibrating sensing devices and instruments used in recording performance tests. Calibration of functional and indicating devices for equipment operations are covered under equipment test work sheets.
2. Standard instruments used for calibrating sensing devices must have valid calibration. Record calibration data in Block A.
3. All instruments and sensing devices must be calibrated on bench or in field with standard instruments. At least two points covering the entire range of normal operation should be calibrated. This work sheet lists recommended calibration points. After final calibration, record data in Block B.

A. Standard instruments data (copy from standard instrument records):

| | type | Make, model & serial no. | Calib. Date | Calib. by (organization) |
|---|---|---|---|---|
| Temperature | | | | |
| Humidity | | | | |
| Pressure | | | | |
| Power | | | | |
| Others | | | | |

B. Final calibration data (set temperature listed below may be changed according to application):

| | | Low point | | | High point | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Instrument or sensing Device | Approx. Calib Point | Std Inst Reading | Final Calib Reading | Approx. Calib Point | Std Inst Reading | Final Calib Reading | No. |
| | Temperature, F: | | | | | | | |
| 1 | Water (for chilled, condenser, steam condensate, and hot) | 32 | | | 200 | | | 1 |
| 2 | Low pressure steam | 200 | | | 300 | | | 2 |
| 3 | Hot water for absorption machine | 200 | | | 300 | | | 3 |
| 4 | Refrigerant for remote condenser | 100 | | | 200 | | | 4 |

TEST WORK SHEET WS 3C-1 -- INSTRUMENT CALIBRATION FOR COOLING PLANT
(continued)

Page 2

Date__________

| No. | Instrument or sensing Device | Low point: Approx. Set Temp | Low point: Std Inst Reading | Low point: Final Calib Reading | High point: Approx. Set Temp | High point: Std Inst Reading | High point: Final Calib Reading | No. |
|---|---|---|---|---|---|---|---|---|
| | Air humidity: | | | | | | | |
| 5 | Wet bulb temp, F | 35#1 | | | 75#1 | | | 5 |
| 6 | Relative humidity, % | 30#2 | | | 90#2 | | | 6 |
| | Flow: | | | | | | | |
| 7 | Flow sensing devices for water, steam, and refrigerant, gpm | #3 | | | #4 | | | 7 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 8 | Pressure sensing devices, see Below | | | | | | | 8 |
| | Pressure: | | | | | | | |
| 9 | Water static pressure, ft w.c. or psi | #5 | | | #6 | | | 9 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 10 | Refrigerant static pressure, psi | #7 | | | #8 | | | 10 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 11 | Water pressure for velocity sensing, in. w.c. | 0 | | | 20 | | | 11 |
| | Other devices: | | | | | | | |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |

Notes:
- #1 Within dry bulb temperature of 10 - 100 F
- #2 Within dry bulb temperature of 35 - 100 F
- #3 25% below specified
- #4 25% above specified
- #5 25% below specified
- #6 25% above specified
- #7 25 psig below specified
- #8 25 psig above specified

Comments:______________________________________________________________

________________________________________________________________________

________________________________________________________________________

## 3.4 TEST WORK SHEET WS 3C-2 -- CENTRIFUGAL CHILLER (SAFETY CONTROL TEST)

Chiller no.________________ Date__________
Make & model_______________ Test agent________________
Serial no._________________ Commissioning team_______________
Motor serial no.___________ _______________
Refrigerant________________ _______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Check compressor electric voltage balance: | | | | |
| | 1a Between phases 1 & 2:_____V (A) | | | | 1a |
| | Between phases 2 & 3:_____V (B) | | | | |
| | Between phases 1 & 3:_____V (C) | | | | |
| | 1b Calculate average voltage (A + B + C) / 3 = ______V (D) | | | | 1b |
| | 1c Calculate deviation | | | | 1c |
| | (A - D) / D x 100 = _____% (E) | | | | |
| | (B - D) / D x 100 = _____% (F) | | | | |
| | (C - D) / D x 100 = _____% (G) | | | | |
| | 1d E, F, or G not over +/- 1% | | | | 1d |
| 2 | Disconnect power to compressor | | | | 2 |
| 3 | Connect power to control panel | | | | 3 |
| 4 | Test pilot lights and alarms | | | | 4 |
| 5 | Turn compressor on (simulated) | | | | 5 |
| 6 | Test refrig low temp cutout (* F) Actual cutin___F, Cutout___F | | | | 6 |
| 7 | Test refrig high temp cutout (* F) Actual cutin___F, Cutout___F | | | | 7 |
| 8 | Test ch w low temp cutout (* F) Actual cutin___F, Cutout___F | | | | 8 |
| 9 | Test oil heater thermostat (* F) Actual cutin___F, Curout___F | | | | 9 |
| 10 | Test cond high pres cutout (* psi) Actual cutout pres___psi | | | | 10 |
| 11 | Test evap low pres cutout (* psi) Actual cutout pres___psi) | | | | 11 |
| 12 | Test condenser water flow switch | | | | 12 |
| 13 | Test evaporator water flow switch | | | | 13 |
| 14 | Reconnect compressor wiring | | | | 14 |
| 15 | Test low oil pressure safety control circuit | | | | 15 |

## 3.5 TEST WORK SHEET WS 3C-3 -- CENTRIFUGAL CHILLER (AUXILIARY EQUIPMENT TEST)

Page 1

Chiller no.________________ Date__________
Make & model________________ Test agent________________________
Serial no.________________ Commissioning team________________
Motor serial no.____________ ________________
Refrigerant________________ ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Start cond water pump | | | | 1 |
| 2 | Balance cond water flow rate (* gpm)<br>Actual flow rate (____gpm) | | | | 2 |
| 3 | Check ent cond water temp (* F)<br>Actual temp (____F) | | | | 3 |
| 4 | Start ch water pump | | | | 4 |
| 5 | Balance ch water flow rate (* gpm)<br>Actual flow rate (____gpm) | | | | 5 |
| 6 | Check control air pressure<br>Actual pressure (____psi) | | | | 6 |
| | OIL SYSTEM: | | | | |
| 7 | Check oil level | | | | 7 |
| 8 | Turn on oil pump | | | | 8 |
| 9 | Check oil sump temp (* F)<br>Actual temp (____F) | | | | 9 |
| 10 | Check oil temp at bearing (* F)<br>Actual temp (____F) | | | | 10 |
| 11 | Check oil press at bearing (* psi)<br>Actual pressure (____psi) | | | | 11 |
| | PURGE SYSTEM: | | | | |
| 12 | Turn purge system to manual control | | | | 12 |
| 13 | Test by following mfg recommendations | | | | 13 |

COMMENTS:________________________________________________________
_________________________________________________________________
_________________________________________________________________

TEST WORK SHEET WS 3C-3 -- CENTRIFUGAL CHILLER (AUXILIARY EQUIPMENT TEST) - (continued) Page 2

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | PUMPOUT SYSTEM: | | | | |
| 14 | Test by following mfg recommendations | | | | 14 |
| | If reciprocating compressor is provided: | | | | |
| 14a | Turn pumpout system condenser water valves on | | | | 14a |
| 14b | Run pumpout compressor for 1/2 hour | | | | 14b |
| 14c | Record and compare running conditions with recommendations:<br>Discharge pressure (* psi/____psi)<br>Suction pressure (* psi/____psi)<br>Oil pressure (* psi/____psi)<br>Ent water temp (* F/____ F)<br>Lvg water temp (* F/____ F) | | | | 14c |
| | BRUSH CLEANING SYSTEM: | | | | |
| 15 | Attach thermometers and insulation at both side of diverting valve | | | | 15 |
| 16 | Take 3 sets of temperature readings<br>_____ F, _____ F, _____ F | | | | 16 |
| 17 | Compare measured temperature<br>Temp difference not to exceed 0.5 F | | | | 17 |

COMMENTS:______________________________________________

## 3.6 TEST WORK SHEET WS 3C-4 -- CENTRIFUGAL CHILLER (FULL LOAD TEST)

Page 1

Chiller no.________________  Date__________
Make & model________________  Test agent________________________
Serial no.________________  Commissioning team________________
Motor serial no.____________  ________________
Refrigerant________________  ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Be sure cond w and ch w pumps are on | | | | 1 |
| 2 | Set lvg ch w temp to specified (* F) | | | | 2 |
| 3 | Turn on compressor | | | | 3 |
| 4 | Observe direction of comp rotation | | | | 4 |
| 5 | Load chiller by adding false load and/or valving action using ch w temp diff and comp current draw as guide | | | | 5 |
| 6 | Electric current not exceed demand limit | | | | 6 |
| 7 | Observe compressor vane actuator No hunting appeared | | | | 7 |
| 8 | Run chiller at full load for 1 hr minimum with temp and flow rate stablized as specified, minor adjustment may be necessary | | | | 8 |
| 9 | Take 3 sets of data at 10 min intervals to verify system stablization: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate. Specified values:<br>Lvg ch w temp (* F)<br>Ent ch w temp (* F)<br>Ch w flow rate (* gpm)<br>Ent cond w temp (* F)<br>Lvg cond w temp (* F)<br>Cond w flow rate (* F) | | | | 9 |

TEST WORK SHEET WS 3C-4 -- CENTRIFUGAL CHILLER (FULL LOAD TEST) - (continued)
Page 2

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 1 2 3 | | | | |
| 9a | Chilled water:<br>Lvg ch w temp (_____,______,_______F)<br>Ent ch w temp (_____,______,_______F) or<br>Ch w temp diff (____,______,_______F)<br>Ch w flow rate (_____,_____,______gpm) | | | | 9a |
| 9b | Condenser water:<br>Lvg cond w temp (____,______,______F)<br>Ent cond w temp (_____,_____,_____F) or<br>Cond w temp diff (____,_____,_____F)<br>Cond w flow rate (____,_____,_____gpm) | | | | 9b |
| 10 | Repeat step 9 if necessary until differences between 3 readings are less than the limits. | | | | 10 |
| 11 | Take 3 sets of test data at 10 minute intervals: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate | | | | 11 |
| | 1 2 3 | | | | |
| 11a | Chilled water:<br>Lvg ch w temp (_____,_____,______F)<br>Ent ch w temp (_____,_____,______F) or<br>Ch w temp diff (_____,_____,______F)<br>Ch w flow rate (_____,_____,______gpm)<br>Ent ch w press (_____,_____,______psi)<br>Lvg ch w press (_____,_____,______psi)<br>Evaporator lvg refrigerant temperature (_____,_____,_____F) | | | | 11a |
| 11b | Condenser water:<br>Lvg cond w temp (____,_____,_____F)<br>Ent cond w temp (____,_____,_____F) or<br>Cond w temp diff (____,_____,_____F)<br>Cond w flow rate (____,_____,_____gpm)<br>Ent condw press (____,_____,_____psi)<br>Lvg cond w press (____,_____,_____psi)<br>Cond lvg refrigerant temperature (_____,_____,_____F) | | | | 11b |
| 11c | Electricity:<br>Wattmeter output (____,_____,_____Watt) | | | | 11c |
| 12 | No unusual noise during test | | | | 12 |

TEST WORK SHEET WS 3C-4 -- CENTRIFUGAL CHILLER (FULL LOAD TEST) - (continued)
Page 3

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13 | Calculate average test data: | | | | 13 |
| 13a | Chilled water: | | | | 13a |
| | Lvg ch w temp (________F) | | | | |
| | Ent ch w temp (________F) or | | | | |
| | Ch w temp diff (_______F) | | | | |
| | Ch w flow rate (_______gpm) | | | | |
| | Lvg evap refrignt temp (______F) | | | | |
| | Ent ch w press (_______psi) | | | | |
| | Lvg ch w press (_______psi) | | | | |
| 13b | Condenser water: | | | | 13b |
| | Lvg cond w temp (______F) | | | | |
| | Ent cond w temp (______F) or | | | | |
| | Cond w temp diff (_____F) | | | | |
| | Cond w flow rate (_____gpm) | | | | |
| | Lvg cond refrignt temp (______F) | | | | |
| | Ent cond w press (_____psi) | | | | |
| | Lvg cond w press (_____psi) | | | | |
| 13c | Electricity: | | | | 13c |
| | Wattmeter output (_____Watt) | | | | |
| 14 | Calculate full load capacity & performance: | | | | 14 |
| 14a | Calculations: | | | | 14a |

Test capacity

$(CAP)_t$ = (ch w temp diff) x (ch w flow rate) x 500 Btu/h

$$= \frac{\text{(ch w temp diff) x (ch w flow rate)}}{24} \text{ cooling tons}$$

$$= \frac{(\_\_\_\_\_) \times (\_\_\_\_\_)}{24} = \_\_\_\_\_ \text{ cooling tons}$$

Specified capacity $(CAP)_s$ = * Btu/h or
= * cooling tons

Test power input $(E)_t$ = ________kW

Specified power input $(E)_s$ = * kW

COMMENTS:____________________________________________________________

______________________________________________________________________

TEST WORK SHEET WS 3C-4 -- CENTRIFUGAL CHILLER (FULL LOAD TEST) continued
Page 4

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

Test energy performance = $\frac{(E)_t}{(CAP)_t \text{ in tons}}$ kW/ton = $\frac{\_\_\_\_\_}{\_\_\_\_\_}$

= _____ kW/ton

Specified energy performance = * kW/ton

Test evaporator water pressure drop

$(Pevap)_t$ = water press at evap inlet - water pressure at evap outlet

= _____ - _____ = _____ ft w.c.

Specified evaporator water pressure drop $(P_{evap})_s$ = * ft w.c.

Test condenser water pressure drop

$(P_{cond})_t$ = water press at cond inlet - water pressure at cond outlet

= _____ - _____ = _____ ft w.c.

Specified condenser water pressure drop $(P_{cond})_s$ = * ft w.c.

14b Acceptance criteria: 14b

$(CAP)_t > (CAP)_s$
$(E)_t < (E)_s$
Test energy performance > Specified energy performance
$(P_{evap})_t < (P_{evap})_s$
$(P_{cond})_t < (P_{cond})_s$

COMMENTS:________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

## 3.7 TEST WORK SHEET WS 3C-5 -- CENTRIFUGAL CHILLER (* % PART LOAD AND CAPACITY CONTROL TEST)
Page 1

Make & model________________ Test agent________________________
Serial no.__________________ Commissioning team________________
Motor serial no.____________ __________________
Refrigerant_________________ __________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Ent cond w temp of certain part load may be different from that of full load (See specs.). If so, reset cooling tower control to supply the required ent cond w temp (* F) | | | | 1 |
| 2 | Reduce chiller load by decreasing false load and/or valving action using ch w temp diff and comp current draw as guide | | | | 2 |
| 3 | Run chiller at desired part load for 1 hr minimum with temp and flow rate stablized as specified, minor adjustment may be necessary | | | | 3 |
| 4 | Observe amperage readings of compressor while load is being reduced. Readings should not fluctuate | | | | 4 |
| 5 | Take 3 sets of data at 10 min intervals to verify system stablization: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate. Specified values:<br>Lvg ch w temp (* F)<br>Ent ch w temp (* F)<br>Ch w flow rate (* gpm)<br>Lvg cond w temp (* F)<br>Ent cond w temp (* F)<br>Cond w flow rate (* gpm) | | | | 5 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 3C-5 -- CENTRIFUGAL CHILLER (* % PART LOAD AND CAPACITY CONTROL TEST) continued

Page 2

Chiller no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 1 2 3 | | | | |
| 5a | Chilled water:<br>Lvg ch w temp (_____,_____,_______F)<br>Ch w temp diff (_____,_____,______F) or<br>Ent ch w temp (_____,_____,_______F)<br>Ch w flow rate (____,_____,_______gpm) | | | | 5a |
| | 1 2 3 | | | | |
| 5b | Condenser water:<br>Ent cond w temp (____,_____,______F)<br>Cond w temp diff (____,_____,_____F) or<br>Lvg cond w temp (____,_____,______F)<br>Cond w flow rate (____,_____,_____gpm) | | | | 5b |
| 6 | Repeat step 7 until the differences between the 3 readings are less than the limits. | | | | 6 |
| 7 | Take 3 sets of test data at 10 minute intervals: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate | | | | 7 |
| | 1 2 3 | | | | |
| 7a | Chilled water:<br>Lvg ch w temp (_____,______,______F)<br>Ent ch w temp (_____,______,______F) or<br>Ch w temp diff (_____,______,_____F)<br>Ch w flow rate (____,_____,_______gpm) | | | | 7a |
| 7b | Condenser water:<br>Lvg cond w temp (_____,_____,_____F)<br>Ent cond w temp (_____,_____,_____F) or<br>Cond w temp diff (_____,_____,____F)<br>Cond w flow rate (____,_____,_____gpm) | | | | 7b |
| 7c | Electricity:<br>Wattmeter output (____,_____,_____Watt) | | | | 7c |
| 8 | After all part load tests, remove false load and/or restore valves to their normal operating conditions | | | | 8 |

COMMENTS:____________________________________________________________

______________________________________________________________________

______________________________________________________________________

TEST WORK SHEET WS 3C-5 -- CENTRIFUGAL CHILLER (* % PART LOAD AND CAPACITY CONTROL TEST) continued
Page 3

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9 | Turn lvg ch w thermostat up till compressor starting coastdown. Then restore this thermostat to its original position. count time between compressor coastdown and restart (* min.)<br>Actual delay time_____min. | | | | 9 |
| 10 | During entire part load tests, no unusual noise, vibration and fluctuating compressor current draw | | | | 10 |
| 11 | Turn compressor off, record oil press at bearing (required minimum * psi)<br>Actual bearing oil pressure (_____psi) | | | | 11 |
| 12 | Calculate average test data: | | | | 12 |
| 12a | Chilled water:<br>Lvg ch w temp (________F)<br>Ch w temp diff (_______F) or<br>Ent ch w temp (________F)<br>Ch w flow rate (_______gpm) | | | | 12a |
| 12b | Condenser water:<br>Ent cond w temp (______F)<br>Cond w temp diff (_____F) or<br>Lvg cond w temp (______F)<br>Cond w flow rate (_____gpm) | | | | 12b |
| 12c | Electricity:<br>Wattmeter output (_____Watt) | | | | 12c |

COMMENTS:_______________________________________________

TEST WORK SHEET WS 3C-5 -- CENTRIFUGAL CHILLER (* % PART LOAD AND CAPACITY CONTROL TEST) continued
Page 4

Chiller no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13 | Calculate part load capacity & performance: | | | | 13 |
| 13a | Calculations: | | | | 13a |

Test capacity

$(CAP)_t$ = (ch w temp diff) x (ch w flow rate) x 500 Btu/h

$$= \frac{\text{(ch w temp diff) x (ch w flow rate)}}{24} \text{ cooling tons}$$

$$= \frac{\_\_\_\_\_ \text{ x } \_\_\_\_\_}{24} = \_\_\_\_\_ \text{ cooling tons}$$

Specified capacity $(CAP)_s$ = * Btu/h or
= * cooling tons

Test power input $(E)_t$ = ________kW

Specified power input $(E)_s$ = * kW

$$\text{Test energy performance} = \frac{(E)_t}{(CAP)_t \text{ in tons}} \text{ kW/ton}$$

$$= \frac{\_\_\_\_\_}{\_\_\_\_\_} = \_\_\_\_\_ \text{ kw/ton}$$

Specified energy performance = * kW/ton

13b Acceptance criteria: 13b

$(CAP)_t > (CAP)_s$
$(E)_t < (E)_s$
Test energy performance > Specified energy performance

COMMENTS:______________________________________

## 3.8 TEST WORK SHEET WS 3C-6 -- CENTRIFUGAL CHILLER ( COOLING PLANT SYSTEM TEST)

Chiller no.________________ Date__________
Make & model________________ Test agent________________________
Serial no.________________ Commissioning team________________
Motor serial no.____________ ________________
Refrigerant________________ ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.
3. Cooling plant system tests depend very much on system design of the project. The steps of this form may need modification. Consult specification and dwgs for changes needed.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Test chiller, ch w pump, cond w pump, and cooling tower interlock (See specification and dwgs for interlocking arrangement) | | | | 1 |
| 2 | Test lead-lag machine by changing sequencing switch positions and observing chiller operation | | | | 2 |
| 3 | If system has automatic start by sensing outside air temp, place outside temp sensor in liquid temp bath at specified temp (* F). Verify chiller start. Actual temp chiller starts _____F. | | | | 3 |
| 4 | If system has timer operated automatic start, turn timer to starting time to verify chiller start. | | | | 4 |

COMMENTS:________________________________________________________________
________________________________________________________________
________________________________________________________________

## 3.9 TEST WORK SHEET WS 3D-1 -- RECIPROCATING CHILLER (SAFETY CONTROL AND GENERAL OPERATIONAL TESTS)

Page 1

Chiller no.________________ Date__________
Make & model________________ Test agent________________
Serial no.________________ Commissioning team________________
Motor serial no.____________ ________________
Refrigerant________________ ________________
Condensing: Water____ Air____ Evap____
Compressor voltage (phase 1-2)________V
Compressor voltage (phase 1-3)________V
Compressor coltage (phase 2-3)________V

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Check electric voltage balance: | | | | |
| 1a | Between phases 1 & 2:______V (A)<br>Between phases 2 & 3:______V (B)<br>Between phases 1 & 3:______V (C) | | | | 1a |
| 1b | Calculate average voltage<br>(A + B + C) / 3 = _______V (D) | | | | 1b |
| 1c | Calculate deviation<br>(A - D) / D x 100 = _____% (E)<br>(B - D) / D x 100 = _____% (F)<br>(C - D) / D x 100 = _____% (G) | | | | 1c |
| 1d | E, F, or G not over +/- 1% | | | | 1d |
| 2 | Check crankcase heater status (feel compressor warmth) | | | | 2 |
| 3 | Check compressor oil level | | | | 3 |
| 4 | Test all pilot lights and alarms | | | | 4 |
| 5 | Start condenser water pump (water cooled) | | | | 5 |
| 6 | Check and adjust condenser water flow rate (water cooled)(* gpm) ____ gpm | | | | 6 |
| 7 | Check condenser water temp (water cooled) (* F) ____ F | | | | 7 |
| 8 | Start evaporative cooler (evaporatively cooled) | | | | 8 |

COMMENTS:________________________________________________

________________________________________________________

TEST WORK SHEET WS 3D-1 -- RECIPROCATING CHILLER (SAFETY CONTROL AND GENERAL OPERATIONAL TESTS) continued
Page 2

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9 | Start chilled water pump | | | | 9 |
| 10 | Check and adjust chilled w flow rate | | | | 10 |
| 11 | Set and check chilled w temperature (* F) ____ F | | | | 11 |
| 12 | Start compressor | | | | 12 |
| 13 | Only first step cylinder loaded when compressor is started | | | | 13 |
| 14 | Check direction of condenser fan ratation (air cooled and evaporatively cooled) | | | | 14 |
| 15 | Test temperature safety controls (if provided): | | | | |
| | 15a Refrig low temp cutout (* F) Actual cutin____F, Cutout____F | | | | 15a |
| | 15b Refrig high temp cutout (* F) Actual cutin____F, Cutout____F | | | | 15b |
| | 15c Ch w low temp cutout (* F) Actual cutin____F, Cutout____F | | | | 15c |
| | 15d Oil heater thermostat (* F) Actual cutin____F, Curout____F | | | | 15d |
| 16 | Test flow safety controls: | | | | 16 |
| | 16a Chilled water flow switch | | | | |
| | 16b Condenser waterflow switch | | | | |
| 17 | Test pressure safety controls: | | | | |
| | 17a High pres cutout (* psi) Actual cutout pres____psi | | | | 17a |
| | 17b Low pres cutout (* psi) Actual cutout pres____psi) | | | | 17b |
| 18 | Check oil level and foaming, record oil pressure (if gage is provided) _____psi (recommended * psi) | | | | 18 |
| 19 | Check refrigerant charge through sight glass | | | | 19 |
| 20 | Load machine by adding false load and/or valving operation | | | | 20 |

COMMENTS:______________________________________________

TEST WORK SHEET WS 3D-1 -- RECIPROCATING CHILLER (SAFETY CONTROL AND GENERAL OPERATIONAL TESTS) continued

Page 3

Chiller no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 21 | Observe chilled water return temp vs. cylinder loading | | | | 21 |
| 22 | Observe electric current draw, it shall not exceed maximum | | | | 22 |
| 23 | Check discharge pressure for over-charge | | | | 23 |
| 24 | Test head pressure control (air cooled and remote condenser): | | | | 24 |
| | 24a Temperature sensed control | | | | |
| | 24b Pressure sensed control | | | | |
| 25 | Test lead-lag control | | | | 25 |
| 26 | Test automatic start control: | | | | |
| | 26a Outside air temperature operated (* F) ____ F | | | | 26a |
| | 26b Timer operated | | | | 26b |

COMMENTS:______________________________________________

______________________________________________

______________________________________________

## 3.10 TEST WORK SHEET WS 3D-2 -- RECIPROCATING CHILLER (FULL LOAD TEST)

Page 1

Chiller no.________________ Date__________
Make & model_______________ Test agent________________________
Serial no._________________ Commissioning team________________
Motor serial no.___________ ________________
Refrigerant________________ ________________
Condensing: Water____ Air____ Evap____

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Add false load til chiller is fully loaded | | | | 1 |
| 2 | Adjust and check chilled water flow rate (* gpm) _____ gpm | | | | 2 |
| 3 | Adjust and check condenser water flow rate (water cooled) (* gpm) _____ gpm | | | | 3 |
| 4 | Adjust and check discharge pressure, (air cooled and evaporatively cooled) (* psi) _____ psi | | | | 4 |
| 5 | Find equvilent saturated discharge temperature, _____ F (air cooled and evaporatively cooled) | | | | 5 |
| 6 | Run chiller at full load for 1 hr minimum with temp and flow rate stablized as specified, minor adjustment may be necessary | | | | 6 |

COMMENTS:____________________________________________
_____________________________________________________
_____________________________________________________

TEST WORK SHEET WS 3D-2 -- RECIPROCATING CHILLER (FULL LOAD TEST) continued
Page 2

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7 | Take 3 sets of data at 10 min intervals to verify system stablization: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate<br>Specified values for all units:<br>Lvg ch w temp (* F)<br>Ent ch w temp (* F)<br>Ch w flow rate (* gpm)<br>For water cooled units:<br>Lvg cond w temp (* F)<br>Ent cond w temp (* F)<br>Cond w flow rate (* gpm)<br>For air cooled units:<br>Saturated discharge pressure (* psi) | | | | 7 |
| | 1 2 3 | | | | |
| 7a | Chilled water:<br>Lvg ch w temp (_____,______,_______F)<br>Ch w temp diff (____,______,_______F) or<br>Ent ch w temp (_____,______,_______F)<br>Ch w flow rate (_____,_____,______gpm) | | | | 7a |
| 7b | For water cooled condenser:<br>Ent cond w temp (____,______,______F)<br>Cond w temp diff (____,_____,_____F) or<br>Lvg cond w temp (_____,_____,_____F)<br>Cond w flow rate (____,_____,_____gpm) | | | | 7b |
| 7c | For air or evap cooled condenser:<br>Saturated discharge pressure<br>(_____,_____,_____psi)<br>Saturated discharge temperature<br>(_____,_____,_____F) | | | | 7c |
| 8 | Repeat step 7 if necessary until differences between 3 readings are less than the limits. | | | | 8 |

COMMENTS:_______________________________________________

_______________________________________________

_______________________________________________

TEST WORK SHEET WS 3D-2 -- RECIPROCATING CHILLER (FULL LOAD TEST) continued
Page 3

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9 | Take 3 sets of test data at 10 minute intervals: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate | | | | 9 |
| | 1 2 3 | | | | |
| 9a | Chilled water:<br>Lvg ch w temp (_____,_____,_____F)<br>Ch w temp diff (_____,_____,_____F) or<br>Ent ch w temp (_____,_____,_____F)<br>Ch w flow rate (_____,_____,_____gpm)<br>Ent ch w press (_____,_____,_____psi)<br>Lvg ch w press (_____,_____,_____psi) | | | | 9a |
| 9b | Electricity:<br>Wattmeter output (_____,_____,_____Watt) | | | | 9b |
| 9c | Water cooled condenser:<br>Ent cond w temp (____,_____,_____F)<br>Cond w temp diff (____,_____,_____F) or<br>Lvg cond w temp (____,_____,_____F)<br>Cond w flow rate (____,_____,_____gpm)<br>Ent cond w press (____,_____,_____psi)<br>Lvg cond w press (____,_____,_____psi) | | | | 9c |
| | 1 2 3 | | | | |
| 9d | Air or evap cooled condenser:<br>Saturated discharge pressure<br>(_____,_____,_____psi)<br>Saturated discharge temperature<br>(_____,_____,_____F)<br>Ambient air dry bulb temperature<br>(_____,_____,_____F)<br>Ambient air wet bulb temperature<br>(_____,_____,_____F) | | | | 9d |

COMMENTS:_______________________________________________

TEST WORK SHEET WS 3D-2 -- RECIPROCATING CHILLER (FULL LOAD TEST) continued
Page 4

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 10 | Calculate average test data: | | | | 10 |
| 10a | Chilled water:<br>Lvg ch w temp (________F)<br>Ch w temp diff (_______F) or<br>Ent ch w temp (________F)<br>Ch w flow rate (_______gpm)<br>Ent ch w press (_______psi)<br>Lvg ch w press (_______Psi) | | | | 10a |
| 10b | Electricity:<br>Wattmeter output (_____Watt) | | | | 10b |
| 10c | Water cooled condenser:<br>Ent cond w temp (______F)<br>Cond w temp diff (_____F) or<br>Lvg cond w temp (______F)<br>Cond w flow rate (_____gpm)<br>Ent cond w press (_____psi)<br>Lvg cond w press (_____psi) | | | | 10c |
| 10d | Air or evap cooled condenser:<br>Saturated discharge temp (_____F)<br>Ambient air dry bulb temp (_____F)<br>Ambient air wet bulb temp (_____F) | | | | 10d |
| 11 | During entire full load tests, no unusual noise, vibration | | | | 11 |
| 12 | Calculate full load capacity & performance: | | | | 12 |
| 12a | Calculations: | | | | 12a |

Test capacity

$$(CAP)_t = (\text{ch w temp diff}) \times (\text{ch w flow rate}) \times 500 \text{ Btu/h}$$

$$= \frac{(\text{ch w temp diff}) \times (\text{ch w flow rate})}{24} \text{ cooling tons}$$

$$= \frac{\_\_\_\_ \times \_\_\_\_}{24} = \_\_\_\_ \text{ cooling tons}$$

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 3D-2 -- RECIPROCATING CHILLER (FULL LOAD TEST) continued
Page 5

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

Specified capacity $(CAP)_s$ = * Btu/h or
= * cooling tons

Test power input $(E)_t$ = ________kW

Specified power input $(E)_s$ = * kW

Test energy performance = $\dfrac{(E)_t}{(CAP)_t \text{ in tons}}$ kW/ton

= $\dfrac{\_\_\_\_}{\_\_\_\_}$ = _____ kW/ton

Specified energy performance = * kW/ton

Test evaporator water pressure drop
$(P_{evap})_t$ = water press at evap inlet - water press at evap outlet
= _____ - _____ = _____ ft w.c.
Specified evaporator pressure drop $(P_{evap})_s$ = * ft w.c.

Test condenser water pressure drop (water cooled only)
$(P_{cond})_t$ = water press at cond inlet - water press at cond outlet
= _____ - _____ = _____ ft w.c.
Specified condenser pressure drop $(P_{cond})_s$ = * ft w.c.

12b Acceptance criteria:

$(CAP)_t > (CAP)_s$
$(E)_t < (E)_s$
Test energy performance > Specified energy performance
$(P_{evap})_t < (P_{evap})_s$
$(P_{cond})_t < (P_{cond})_s$ (water cooled only)

COMMENTS:____________________________________________

## 3.11 TEST WORK SHEET WS 3D-3 -- RECIPROCATING CHILLER (* % PART LOAD TEST)

Page 1

Chiller no.________________ Date__________

Make & model________________ Test agent____________________

Serial no.________________ Commissioning team________________

Motor serial no.____________ ________________

Refrigerant________________ ________________

Condensing: Water____ Air____ Evap____

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Reduce chiller load to specified part load and adjust condenser water temp (water cooled) or saturated discharge temp (air or evap cooled) to specified or those of the Manual | | | | 1 |
| 2 | Run chiller at part load for 1 hr minimum with temp and flow rate stablized as specified, minor adjustment may be necessary | | | | 2 |
| 3 | Take 3 sets of data at 10 min intervals to verify system stablization: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate<br>Specified values for all units:<br>Lvg ch w temp (* F)<br>Ent ch w temp (* F)<br>Ch w flow rate (* gpm)<br>For water cooled units:<br>Lvg cond w temp (* F)<br>Ent cond w temp (* F)<br>Cond w flow rate (* gpm)<br>For air cooled units:<br>Saturated discharge pressure (* psi) | | | | 3 |

COMMENTS:______________________________________________

TEST WORK SHEET WS 3D-3 -- RECIPROCATING CHILLER (* % PART LOAD TEST)
continued
Page 2

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 1 2 3 | | | | |
| 3a | Lvg ch w temp (_____,______,_______F)<br>Ch w temp diff (____,______,_______F) or<br>Ent ch w temp (_____,______,_______F)<br>Ch w flow rate (_____,_____,______gpm) | | | | 3a |
| 3b | Water cooled Condenser:<br>Ent cond w temp (____,______,______F)<br>Cond w temp diff (____,_____,_____F) or<br>Lvg cond w temp (____,_____,_____F)<br>Cond w flow rate (____,_____,_____gpm) | | | | 3b |
| 3c | Air or evap cooled condenser:<br>Saturated discharge pressure<br>(_____,_____,_____psi)<br>Saturated discharge temperature<br>(_____,_____,_____F) | | | | 3c |
| 4 | Repeat step 3 if necessary until differences between 3 readings are less than the limits. | | | | 4 |
| 5 | Take 3 sets of test data at 10 minute intervals: tolerances from specified values not to exceed 1 F for temp and 5% for flow rate | | | | 5 |
| | 1 2 3 | | | | |
| 5a | Chilled water:<br>Lvg ch w temp (_____,______,_______F)<br>Ch w temp diff (____,______,_______F) or<br>Ent ch w temp (_____,______,_______F)<br>Ch w flow rate (_____,_____,______gpm) | | | | 5a |

COMMENTS:________________________________________________________________

TEST WORK SHEET WS 3D-3 -- RECIPROCATING CHILLER (* % PART LOAD TEST)
continued
Page 3

Chiller no.__________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 5b | Electricity: | | | | 5b |
| | Wattmeter output (_____,_____,_____Watt) | | | | |
| 5c | Water cooled condenser: | | | | 5c |
| | Ent cond w temp (____,______,______F) | | | | |
| | Cond w temp diff (____,_____,_____F) or | | | | |
| | Lvg cond w temp (_____,_____,_____F) | | | | |
| | Cond w flow rate (____,_____,_____gpm) | | | | |
| 5d | Air or evap cooled condenser: | | | | 5d |
| | Saturated discharge temperature (_____,_____,_____psi) | | | | |
| | Saturated discharge temperature (_____,_____,_____F) | | | | |
| | Ambient air dry bulb temperature (_____,_____,_____F) | | | | |
| | Ambient air wet bulb temperature (_____,_____,_____F) | | | | |
| 6 | Calculate average test data: | | | | 6 |
| 6a | Chilled water: | | | | 6a |
| | Lvg ch w temp (________F) | | | | |
| | Ch w temp diff (_______F) or | | | | |
| | Ent ch w temp (________F) | | | | |
| | Ch w flow rate (_______gpm) | | | | |
| 6b | Electricity: | | | | 6b |
| | Wattmeter output (_____Watt) | | | | |
| 6c | Water cooled condenser: | | | | 6c |
| | Ent cond w temp (______F) | | | | |
| | Cond w temp diff (_____F) or | | | | |
| | Lvg cond w temp (______F) | | | | |
| | Cond w flow rate (_____gpm) | | | | |
| 6d | Air or evap cooled condenser: | | | | 6d |
| | Saturated discharge temp (_____F) | | | | |
| | Ambient air dry bulb temp (_____F) | | | | |
| | Ambient air wet bulb temp (_____F) | | | | |

COMMENTS:_____________________________________________________________

_____________________________________________________________

_____________________________________________________________

TEST WORK SHEET WS 3D-3 -- RECIPROCATING CHILLER (* % PART LOAD TEST) continued

Page 4

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7 | During entire part load tests, no unusual noise, vibration | | | | 7 |
| 8 | Calculate part load capacity & performance: | | | | 8 |
| 8a | Calculations: | | | | 8a |

Test capacity

$(CAP)_t$ = (ch w temp diff) x (ch w flow rate) x 500 Btu/h

$$= \frac{\text{(ch w temp diff) x (ch w flow rate)}}{24} \text{ cooling tons}$$

$$= \frac{\_\_\_\_ \times \_\_\_\_}{24} = \_\_\_\_ \text{ cooling tons}$$

Specified capacity $(CAP)_s$ = * Btu/h or
= * cooling tons

Test power input $(E)_t$ = ________kW

Specified power input $(E)_s$ = * kW

$$\text{Test energy performance} = \frac{(E)_t}{(CAP)_t \text{ in tons}} \text{ kW/ton}$$

$$= \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_ \text{ kW/ton}$$

Specified energy performance = * kW/ton

8b Acceptance criteria: 8b

$(CAP)_t > (CAP)_s$
$(E)_t < (E)_s$
Test energy performance > Specified energy performance

COMMENTS:________________________________________

## 3.12 TEST WORK SHEET WS 3E-1 -- ABSORPTION CHILLER (GENERAL OPERATIONAL TESTS)

Page 1

Chiller no.________________ Date__________
Make & model________________ Test agent________________________
Serial no.________________ Commissioning team________________
Energy source: Steam________psi ________________
Hot water____ F ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Test low temp cutout (* F)<br>Actual cutin___F, cutout___F | | | | 1 |
| 2 | Test other temp safety control (See specs for requirements) (* F)<br>Actual cutin___F, cutout___F | | | | 2 |
| 3 | Check interlocking of ch w cond w pumps and cooling tower (See spec and dwgs for requirements) | | | | 3 |
| 4 | Test flow safety control: | | | | |
| | 4a Chilled water flow switch | | | | 4a |
| | 4b Condenser water flow switch | | | | 4b |
| 5 | Test pilot lights and alarms | | | | 5 |
| 6 | Adjust and check chilled water flow rate | | | | 6 |
| 7 | Adjust and check condenser water flow rate (* gpm) _____ gpm | | | | 7 |
| 8 | Start chiller | | | | 8 |
| 9 | Apply load gradually until chiller is fully loaded | | | | 9 |
| 10 | If steam is energy source and demand limit is specified, check steam flow rate (* % full load) _____ lb/h | | | | 10 |

COMMENTS:______________________________________________________________
______________________________________________________________________
______________________________________________________________________

TEST WORK SHEET WS 3E-1 -- ABSORPTION CHILLER (GENERAL OPERATIONAL TESTS) continued

Page 2

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 11 | After chiller is operating under stable conditions, withdraw solution samples from generator and absorber | | | | 11 |
| 12 | Analyze sample concentration and compare with manufacturer's recommendations<br>Generator (* %) _____ %<br>Absorber (* %) _____ % | | | | 12 |
| 13 | Operate purge system and check for hydrogen presence, purge system should be on for at least 1 hr | | | | 13 |
| 14 | Determin fouling condition of condenser tubes (See Guide) | | | | 14 |

COMMENTS:____________________________________________

## 3.13 TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST)

Page 1

Chiller no.________________ Date__________
Make & model________________ Test agent________________________
Serial no.__________________ Commissioning team________________
Energy source: Steam________psi ________________
Hot water____ F ________________
Load: Full load____,____% part load____

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Adjust machine load and chilled water temp setting to the desired testing load and temp (* F)____ F | | | | 1 |
| 2 | Check and adjust chilled water flow rate (* gpm) _____ gpm | | | | 2 |
| 3 | Check and adjust condenser water flow rate (* gpm) _____ gpm | | | | 3 |
| 4 | Adjust condenser water temp control to obtain specified temp entering absorber (* F) _____ F | | | | 4 |
| 5 | For chiller with hot water as energy source, measure and adjust water temp to specified (* F) _____ F | | | | 5 |
| 6a | For chiller with steam as energy source, measure steam pressure at control valve (* psig) _____ psig | | | | 6a |
| 6b | Measure steam temp at control valve _____ F | | | | 6b |
| 6c | Determine quality of steam from steam table, it must be saturated or superheated | | | | 6c |
| 7 | Run chiller for 1 hr minimum with temp and flow rate stablized as specified, minor adjustment may be necessary | | | | 7 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST) continued

Page 2

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | Take 3 sets of data at 10 min intervals to verify system stablization: tolerances from specified values not to exceed 1 F for temp, 5% for flow rate, and 0.2 psig for steam pressure | | | | 8 |

Specified values:
Lvg ch w temp (* F)
Ent ch w temp (* F)
Ch w flow rate (* gpm)
Ent cond w temp (* F)
Lvg cond w temp (* F)
Cond w flow rate (* gpm)
Ent hot w temp (* F)
Lvg hot w temp (* F)
Steam pressure (* psi)

1 2 3

8a Chilled water: 8a
Lvg ch w temp (_____,______,_______F)
Ent ch w temp (_____,______,_______F) or
Ch w temp diff (____,______,_______F)
Ch w flow rate (_____,_____,______gpm)

8b Condenser water: 8b
Lvg cond w temp (_____,_____,_____F)
Ent cond w temp (____,______,______F) or
Cond w temp diff (____,_____,_____F)
Cond w flow rate (____,_____,_____gpm)

8c Hot water: 8c
Lvg hot w temp (_____,_____,_____F)
Ent hot w temp (_____,_____,_____F) or
Hot w temp diff (_____,_____,_____F)

8d Steam: 8d
Steam pressure (_____,_____,_____psi)

COMMENTS:________________________________________

TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST) continued

Page 3

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9 | Repeat step 8 if necessary until differences between 3 readings are less than the tolerances | | | | 9 |
| 10 | Take 3 sets of test data at 10 minute intervals: tolerances from specified values not to exceed 1 F for temp, 5% for flow rate, and 0.2 psig for steam pressure | | | | 10 |

1 2 3

10a Chilled water: 10a

Lvg ch w temp (_____,_____,______F)
Ent ch w temp (_____,_____,______F) or
Ch w temp diff (_____,_____,______F)
Ch w flow rate (_____,_____,_____gpm)
Full load only:
Ent ch w press (_____,_____,_____psi)
Lvg ch w press (_____,_____,_____psi)

10b Condenser water: 10b

Lvg cond w temp (_____,_____,_____F)
Ent cond w temp (_____,_____,_____F) or
Cond w temp diff(_____,_____,_____F)
Cond w flow rate(_____,_____,_____F)
Full load only:
Ent cond w press (_____,_____,_____psi)
Lvg cond w press (_____,_____,_____psi)

10c Electricity: 10c

Wattmeter output (_____,_____,_____Watt)

10d Hot water: 10d

Lvg Hot w temp (_____,_____,_____F)
Ent hot w temp (_____,_____,_____F) or
Hot w temp diff (_____,_____,_____F)
Hot w flow rate (_____,_____,_____gpm)
Full load only:
Ent hot w press (_____,_____,_____psi)
Lvg hot w press (_____,_____,_____psi)

COMMENTS:________________________________________________

TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST) continued

Page 4

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 10e | Steam and condensate: | | | | 10e |
| | Steam pressure (_____,_____,_____psig) | | | | |
| | Steam temperature(_____,_____,_____F) | | | | |
| | Steam flow rate (____,____,____ lb/hr) | | | | |
| | Condensate temp (_____,_____,_____F) | | | | |
| 11 | No unusual noise and vibration noticed | | | | 11 |
| 12 | Calculate average test data: | | | | 12 |
| 12a | Chilled water: | | | | 12a |
| | Lvg ch w temp (________F) | | | | |
| | Ent ch w temp (________F) or | | | | |
| | Ch w temp diff (_______F) | | | | |
| | Ch w flow rate (_______gpm) | | | | |
| | Full load only: | | | | |
| | Ent ch w press (_______Psi) | | | | |
| | Lvg ch w press (_______psi) | | | | |
| 12b | Condenser water: | | | | 12b |
| | Lvg cond w temp (______F) | | | | |
| | Ent cond w temp (______F) or | | | | |
| | Cond w temp diff (_____F) | | | | |
| | Cond w flow rate (_____gpm) | | | | |
| | Full load only: | | | | |
| | Ent cond w press (_____Psi) | | | | |
| | Lvg cond w press (_____psi) | | | | |
| 12c | Hot water: | | | | 12c |
| | Lvg hot w temp (______F) | | | | |
| | Ent hot w temp (______F) or | | | | |
| | Hot w temp diff (_____F) | | | | |
| | Hot w flow rate (_____gpm) | | | | |
| | Full load only: | | | | |
| | Ent hot w press (_____Psi) | | | | |
| | Lvg hot w press (_____psi) | | | | |
| 12d | Steam and condensate: | | | | 12d |
| | Steam pressure (_____psig) | | | | |
| | Steam temp (_____F) | | | | |
| | Steam flow rate (_____lb/hr) | | | | |
| | Condensate temp (_____F) | | | | |

COMMENTS:______________________________________________________________

_______________________________________________________________________

_______________________________________________________________________

TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST) continued

Page 5

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13 | Calculate capacity & performance: | | | | 13 |
| 13A | Calculations: | | | | 13a |

Capacity:

Test capacity

$(CAP)_t$ = (ch w temp diff) x (ch w flow rate) x 500 Btu/h

$$= \frac{\text{(ch w temp diff) x (ch w flow rate)}}{24} \text{ cooling tons}$$

$$= \frac{\_\_\_\_\_ \text{ x } \_\_\_\_\_}{24} = \_\_\_\_\_ \text{ cooling tons}$$

Specified capacity $(CAP)_s$ = * Btu/h

Heat energy input:

Test energy input for hot water chiller

$(Q_{in})_t$ = (hot w temp diff) x (hot w flow rate) x 500 Btu/h

= _____ x _____ x 500 = _____ Btu/h

Test energy input for steam chiller:

$(Q_{in})_t$ = [(enthalpy of inlet steam) - (condensate temp - 32)] x (steam flow rate) Btu/h

where enthalpy of steam is found from steam table by knowing temp and pressure

Steam flow rate is in lb of steam/h

= [_____ - (_____ - 32)] x _____ = _____ Btu/h

Specified energy input $(Q_{in})_s$ = * Btu/h

COMMENTS:______________________________________________

______________________________________________

______________________________________________

TEST WORK SHEET WS 3E-2 -- ABSORPTION CHILLER (FULL OR PART LOAD TEST) continued

Page 6

Chiller no.________________ Date__________

| No. | Steps | Check Mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

COP of chiller:

Test performance $(COP)_t = \frac{(CAP)_t}{(Q_{in})_t} = \frac{\_\_\_\_\_}{\_\_\_\_\_} =$ _____

Specified performance $(COP)_s$ = *

Heat exchanger pressure drops (Full load test only):

Test evaporator water pressure drop
$(P_{evap})_t$ = water pressure at evap inlet - water pressure at evap outlet
= _____ - _____ = _____ ft w.c.

Specified evaporator pressure drop $(P_{evap})_s$ = * ft w.c.

Test condenser/absorber water pressure drop
$(P_{cond})_t$ = water pressure at cond inlet - water pressure at cond outlet
= _____ - _____ = _____ ft w.c.

Specified cond/absorb pressure drop $(P_{cond})_s$ = * ft w.c.

Test hot water pressure drop
$(P_{hot})_t$ = water pressure at generator inlet - water pressure at generator outlet
= _____ - _____ = _____ ft w.c.

Specified hot water pressure drop $(P_{hot})_s$ = * ft w.c.

13b Acceptance criteria: 13b

$(CAP)_t > (CAP)_s$
$(Q_{in})_t < (Q_{in})_s$
$(COP)_t > (COP)_s$
$(P_{evap})_t < (P_{evap})_s$
$(P_{cond})_t < (P_{cond})_s$
$(P_{hot})_t < (P_{hot})_s$

COMMENTS:________________________________________

## 3.14 TEST WORK SHEET WS 3F-1 -- COOLING TOWER

Page 1

Tower no.________________ Date__________
Make & model______________ Test agent________________________
Serial no.________________ Commissioning team________________
Type: induced draft________ ________________
forced draft__________ ________________
Number of cells_______

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Make sure water distribution is balanced | | | | 1 |
| 2 | Make sure water level in cold water basin is correct | | | | 2 |
| 3 | Check wind velocity,_____mph, do not proceed testing if wind velocity is over 10 mph | | | | 3 |
| 4 | Check air wet bulb temp,_____F, do not proceed testing if wet bulb temp is over or under 10 F of specified (* F) | | | | 4 |
| 5 | Disable condenser water temp control | | | | 5 |
| 6 | Load refrigeration machine to full load (see refrigeration machine test) | | | | 6 |
| 7 | turn off makeup and bleed valves | | | | 7 |
| 8 | Measure and adjust condenser water flow rate to specified (* gpm) _____ gpm | | | | 8 |
| 9 | Measure 3 hot water temp at 10 minute intervals, variations between measurements shall not exceed 0.5 F _____F, _____F,_____F | | | | 9 |
| 10 | Repeat step 9 if variations exceeds limits | | | | 10 |

COMMENTS:________________________________________________________
_________________________________________________________________
_________________________________________________________________

TEST WORK SHEET WS 3F-1 -- COOLING TOWER continued

Page 2

Tower no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 11 | Take 6 sets of test data at 10 min intervals, tolerances between data not to exceed: o.5 F for for water temp, 2 F for air wet bulb temp, and 5% for water flow rate | | | | 11 |

```
                        1      2      3
Cold water temp (_____,_____,_____ F)
Hot water temp  (_____,_____,_____ F) or
Water temp diff (_____,_____,_____ F)
Avg air WB temp (_____,_____,_____ F)#
Water flow rate (_____,_____,_____ gpm)
Wattmeter output(_____,_____,_____ W)
                        4      5      6
Cold water temp (_____,_____,_____ F)
Hot water temp  (_____,_____,_____ F) or
Water temp diff (_____,_____,_____ F)
Avg air WB temp (_____,_____,_____ F)#
Water flow rate (_____,_____,_____ gpm)
Wattmeter output(_____,_____,_____ W)
       # Average of one or more
         stations, see Manual
```

12 Calculate tower load for 6 data sets: 12

Test tower load = (water temp diff) x (water flow rate) x 500 Btu/h

Set 1 = _____ x_____ x 500 = ______ Btu/h
Set 2 = _____ x_____ x 500 = ______ Btu/h
Set 3 = _____ x_____ x 500 = ______ Btu/h
Set 4 = _____ x_____ x 500 = ______ Btu/h
Set 5 = _____ x_____ x 500 = ______ Btu/h
Set 6 = _____ x_____ x 500 = ______ Btu/h

The difference of maximum and minimum calculated tower load not to exceed 5% of minimum.

(max - min) = _____ - _____ = _____

5% x min = 5% x _____ = _____

Repeat test if limit is exceeded.

COMMENTS:______________________________________________________________

_______________________________________________________________________

_______________________________________________________________________

TEST WORK SHEET WS 3F-1 -- COOLING TOWER continued

Page 3

Tower no.____________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13 | Calculate average test data:<br>Cold water temp (_____ F)<br>Hot water temp (_____ F) or<br>Water temp diff (_____ F)<br>Air W B temp (_____ F)<br>Water flow rate (_____ gpm) | | | | 13 |
| 14 | Calculate and compare performance: | | | | 14 |
| 14a | Test tower performance:<br>Test tower range = (water temp diff) or<br>= (hot water temp) - (cold water temp)<br>= _____ - _____ = _____ F<br>Test cooling approach = (cold water temp) - (air WB temp)<br>= _____ - _____ = _____ F | | | | 14a |
| 14b | Compare tower performance:<br>The calculated test results of water range and tower approach are compared with manufacturer submitted curves (see project specs) | | | | 14b |

COMMENTS:______________________________________________________________

_______________________________________________________________________

_______________________________________________________________________

## 3.15 TEST WORK SHEET WS 3F-2 -- REFRIGERANT CONDENSER (AIR COOLED OR EVAPORATIVELY COOLED)

Page 1

Condenser no.______________ Date__________
Make & model______________ Test agent______________
Serial no.______________ Commissioning team______________
Type: Dry coil______________ ______________
Evaporative______________ ______________
Motor size: fan______________
pump______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. * denotes data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Check wind velocity (for evap condenser located outdoor only)_____mph, do not proceed if wind velocity is over 10 mph | | | | 1 |
| 2 | check air wet bulb temp (for evap cond only)_____F, do not proceed if it is over or under 10 F from specified (* F) | | | | 2 |
| 3 | Check air temp _____F, do not proceed if temp is below 80 F | | | | 3 |
| 4 | Make sure water level is correct (evap condenser only) | | | | 4 |
| 5 | Test discharge pressure control (see spec or submittals for details) | | | | 5 |
| | 5a Temperature operated | | | | 5a |
| | 5b Pressure operated | | | | 5b |
| 6 | Disable discharge temp (or pressure) control | | | | 6 |
| 7 | Load refrigeration machine to full load (see refrigeration machine test) | | | | 7 |
| 8 | turn off makeup and bleed valves | | | | 8 |
| 9 | Manipulate shut off valves to direct refrigerant gas through flow measuring device | | | | 9 |
| 10 | Run system for at least 1 hour | | | | 10 |

COMMENTS:______________________________________________

TEST WORK SHEET WS 3F-2 -- REFRIGERANT CONDENSER (AIR COOLED OR EVAPORATIVELY COOLED) continued



Condenser no.______________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 11 | Take 6 sets of test data at 10 min intervals, tolerances between data not to exceed: 2 F for temp and 5% for refrigerant flow rate | | | | 11 |

```
                          1      2      3
Ref inlet temp     (_____,_____,_____ F)
ref inlet press    (_____,_____,_____ F)
Ref outlet temp    (_____,_____,_____ F)
ref outlet press   (_____,_____,_____ F)
Ref flow rate      (_____,_____,_____ lb/hr)
Air DB temp #      (_____,_____,_____ F) or
Air WB temp ##     (_____,_____,_____ F)
Wattmeter    ###   (_____,_____,_____ W)

                          4      5      6
Ref inlet temp     (_____,_____,_____ F)
ref inlet press    (_____,_____,_____ F)
Ref outlet temp    (_____,_____,_____ F)
ref outlet press   (_____,_____,_____ F)
Ref flow rate      (_____,_____,_____ lb/hr)
Air DB temp #      (_____,_____,_____ F) or
Air WB temp ##     (_____,_____,_____ F)
Wattmeter    ###   (_____,_____,_____ W)
```

- # For air cooled condenser only
- ## For evaporative condenser only
- ### Fan elec power (air cooled)
  Fan & pump elec power (evap cooled)

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 12 | Check all 6 outlet conditions of refrigerant: locate outlet temp and press on refrig table or chart, if: a) refrig is not subcooled and b) air DB temp for air cooled or air WB temp for evap cooled is below specified, the condenser is undersized | | | | 12 |

COMMENTS:____________________________________________

TEST WORK SHEET WS 3F-2 -- REFRIGERANT CONDENSER (AIR COOLED OR EVAPORATIVELY COOLED) continued
Page 3

Condenser no.______________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13 | Calculate average data:<br>Ref inlet temp (_____ F)<br>ref inlet press (_____ F)<br>Ref outlet temp (_____ F)<br>ref outlet press(_____ F)<br>Ref flow rate (_____ lb/h)<br>Air DB temp # (_____ F) or<br>Air WB temp ## (_____ F)<br>Wattmeter ### (_____ W) | | | | 13 |
| 14 | Calculate and compare performance: | | | | 14 |
| 14a | Test capacity of air cooled condenser: | | | | 14a |
| 14aa | Enthalpy at inlet $H_{in}$, -- locate inlet temp and press on refrig table or chart _____Btu/lb | | | | 14aa |
| 14ab | Enthalpy at outlet, $H_{out}$ -- locate outlet temp & press on refrig table or chart _____Btu/lb | | | | 14ab |
| 14ac | Test heat rejection rate at test conditions:<br>$Q_t$ = (refrig flow rate) x ($H_{in}$ -$H_{out}$) Btu/h<br>= _____ x (_____ - _____) = _____ Btu/h | | | | 14ac |
| 14ad | Determin test condensing temp by locating refrig inlet pressure on refrig table or chart, _____ F | | | | 14ad |
| 14ae | Test heat rejection rate at specified conditions (in Btu/h): | | | | 14ae |

$$Q_{ts} = \frac{\text{(specified condensing temp)} - \text{(specified outdoor temp)}}{\text{(test condensing temp)} - \text{(test outdoor temp)}} \times Q_t$$

$$= \frac{\_\_\_\_\_ - \_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} \times \_\_\_\_\_ = \_\_\_\_\_ \text{ Btu/h}$$

14b Specified heat rejection rate $Q_s$ = * Btu/h 14b

COMMENTS:______________________________________________

TEST WORK SHEET WS 3F-1 -- REFRIGERANT CONDENSER (AIR COOLED OR EVAPORATIVELY COOLED) continued Page 4

Condenser no.______________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 14c | Test capacity of evaporative condenser: | | | | 14c |
| 14ca | Enthalpy at inlet Hin, -- locate inlet temp and press on refrig table or chart _____Btu/lb | | | | 14ca |
| 14cb | Enthalpy at outlet, Hout -- locate outlet temp & press on refrig table or chart _____Btu/lb | | | | 14cb |
| 14cc | Test heat rejection rate at test conditions: $Q_t$ = (refrig flow rate) x ($H_{in}$ -$H_{out}$) Btu/h = _____ x (_____ - _____) = _____ Btu/h | | | | 14cc |
| 14cd | Determin test condensing temp by locating refrig inlet pressure on refrig table or chart, _____ F | | | | 14cd |
| 14d | Manufacturer supplied capacity at test conditions (same air wet bulb temperature and refrigerant condensing temperature) $Q_s$ = * Btu/hr | | | | 14d |
| 15 | Acceptance criteria: | | | | 15 |
| 15a | Air cooled condenser: $Q_{ts} > Q_s$ | | | | 15a |
| 15b | Evapratively cooled condenser: $Q_t > Q_s$ | | | | 15b |

COMMENTS:______________________________________________

## 4.1 INSPECTION CHECK LIST CL 4A-1 -- BOILER

Page 1

Boiler no.__________________ Date__________

Make & model________________ Inspection agent_________________

Serial no.__________________ Commissioning team_______________

Boiler type_________________ _______________

Heating medium: steam___ water___ _______________

Energy source: oil___ gas___ elec___

Pressure______ psig

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | For all boilers: | | | | |
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify boiler and burner model with submittals | | | | 3 |
| 4 | Tube pulling space adequate | | | | 4 |
| 5 | Other access space adequate (headroom, access doors, manholes, etc) | | | | 5 |
| 6 | Heating plant clean, no fire hazards | | | | 6 |
| 7 | Heating plant ventilation opening proper | | | | 7 |
| 8 | Proper vibration unit installation | | | | 8 |
| 9 | Pipes cleaned before connecting to boiler | | | | 9 |
| 10 | Pipe fittings and accessories complete | | | | 10 |
| 11 | Check valves and flow switches flow direction correct | | | | 11 |
| 12 | Pipes not supported on boiler (special attention to safety valves) | | | | 12 |
| 13 | Gas vent pipe extended to outside | | | | 13 |
| 14 | Protection shields for motor and belts | | | | 14 |
| 15 | Alignment of motor driven components | | | | 15 |
| 16 | Belt tightness | | | | 16 |
| 17 | Lubrication complete and proper | | | | 17 |
| 18 | Thermometers complete | | | | 18 |
| 19 | Pressure gages complete | | | | 19 |
| 20 | Flow meters meet installation requirements | | | | 20 |
| 21 | Thermal insulation complete and no damage | | | | 21 |
| 22 | Insulation for induced draft fan applied | | | | 22 |
| 23 | Surface paint complete, equipment labels complete and legible | | | | 23 |
| 24 | Refractory installed properly | | | | 24 |
| 25 | Control wiring installed properly | | | | 25 |

COMMENTS:________________________________________________________________

_________________________________________________________________________

_________________________________________________________________________

INSPECTION CHECK LIST CL 4A-1 -- BOILER (continued)

Page 2

Boiler no.________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 26 | Mercury switchs leveled correctly | | | | 26 |
| 27 | Control air pressure correct (compressed air control) | | | | 27 |
| 28 | Power wiring installed properly | | | | 28 |
| 29 | All elec components grounded properly | | | | 29 |
| 30 | All electric connections tight | | | | 30 |
| 31 | Size of overcurrent heater in motor starter | | | | 31 |
| 32 | Test run motors for direction of rotation | | | | |
| 32a | fan | | | | 32a |
| 32b | pump | | | | 32b |
| 32c | air compressor | | | | 32c |
| 32d | other motors | | | | 32d |
| 33 | Oil filter clean | | | | 33 |
| 34 | Water treatment maintained | | | | 34 |
| 35 | Blowdown maintained | | | | 35 |
| 36 | No unusual noise & vibration when running | | | | 36 |
| 37 | Test blowdown valves | | | | 37 |
| 38 | Blowdown shows no leak | | | | 38 |
| 39 | Setting of continuous blowdown proper | | | | 39 |
| 40 | Automatic recording and control instruments installed as specified | | | | 40 |
| 41 | Proper calibration of instrumentation | | | | 41 |
| 42 | Ranges, settings, and operations of automatic recording and control instrumantation proper | | | | 42 |
| | Boiler safety relief valve: | | | | |
| 1 | No damage noted | | | | 1 |
| 2 | No leak noted | | | | 2 |
| 3 | Pipe not supported on valve | | | | 3 |
| 4 | Size of discharge pipe adequate | | | | 4 |
| 5 | Valve removed during boiler boiloff | | | | 5 |
| 6 | Valve setting correct | | | | 6 |
| 7 | Field test of valve relief action Note pressure when valve opened____psi | | | | 7 |

COMMENTS:________________________________________

________________________________________

________________________________________

INSPECTION CHECK LIST CL 4A-1 -- BOILER (continued)

Page 3

Boiler no.__________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | For oil and gas fired burners: | | | | |
| 1 | Inspect oil nozzles, igniters, electrodes, etc. | | | | 1 |
| 2 | Fuel -air ratio controller and linkage | | | | 2 |
| 3 | Gas and oil line strainers clean, oil pressure gage indication steady | | | | 3 |
| 4 | Check all valves and switches for correct positions | | | | 4 |
| 5 | Gas pilot flame stable, when draft fan is fully on | | | | 5 |
| 6 | Pilot flame extinguish promptly, when burner is on | | | | 6 |
| 7 | Verify fuel safety valve interlocks | | | | 7 |
| 8 | Verify temperature interlock switches | | | | |
| 8a | Low temperature | | | | 8a |
| 8b | High temperature | | | | 8b |
| 9 | Verify pressure interlock switches | | | | |
| 9a | Low pressure, oil supply line | | | | 9a |
| 9b | Low pressure, atomizing medium pipe | | | | 9b |
| 9c | Low pressure, gas supply pipe | | | | 9c |
| 9d | Low pressure, draft proof | | | | 9d |
| 9e | High pressure, gas supply pipe | | | | 9e |
| 9f | High pressure, steam | | | | 9f |
| 9g | Differential pressure, oil burner | | | | 9g |
| 9h | Other pressure | | | | 9h |
| 10 | Verify automatic gas safety shut-off valve | | | | 10 |
| 11 | Verify time delay action | | | | |
| 11a | Automatic safety shut-off valve | | | | 11a |
| 11b | Flame failure alarm | | | | 11b |
| 11c | Control responses of flame failure | | | | 11c |
| 11d | Purger timer | | | | 11d |
| 12 | Check action and time of automatic fuel safety valve for: | | | | |
| 12a | Power failure (removing valve energy source) | | | | 12a |
| 12b | Pressure interruption (closing manual valve) | | | | 12b |
| 13 | Check low-fire lighting-off | | | | 13 |
| 14 | Check pilot flame detection control | | | | 14 |

COMMENTS:______________________________________________

INSPECTION CHECK LIST CL 4A-1 -- BOILER (continued)

Page 4

Boiler no.__________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 15 | For sectional boilers with multi-port burners and igniters, check light-off action | | | | 15 |
| 16 | Check all indicationg lights: | | | | |
| 16a | Flame failure | | | | 16a |
| 16b | Load demand | | | | 16b |
| 16c | fuel valve position | | | | 16c |
| 16d | Low water | | | | 16d |
| 16e | Draft fan | | | | 16e |
| 16f | Others | | | | 16f |
| | Boiler capacity control: | | | | |
| 1 | Water circulation rate correct | | | | 1 |
| 2 | Oil preheating system working properly | | | | 2 |
| 3 | Oil temperature within limits | | | | 3 |
| 4 | Boiler achieve warm conditions | | | | 4 |
| 5 | Check fuel-air adjustment at low fire | | | | |
| 5a | Set firing rate at minimum | | | | 5a |
| 5b | Perform flue gas analysis | | | | 5b |
| 5c | Check CO and $CO_2$ amounts | | | | 5c |
| 6 | Check fuel-air adjustment at 25% fire | | | | |
| 6a | Set firing rate at 25% | | | | 6a |
| 6b | Perform flue gas analysis | | | | 6b |
| 6c | Check CO and $CO_2$ amounts | | | | 6c |
| 7 | Check fuel-air adjustment at 50% fire | | | | |
| 7a | Set firing rate at 50% | | | | 7a |
| 7b | Perform flue gas analysis | | | | 7b |
| 7c | Check CO and $CO_2$ amounts | | | | 7c |
| 8 | Check fuel-air adjustment at 75% fire | | | | |
| 8a | Set firing rate at 75% | | | | 8a |
| 8b | Perform flue gas analysis | | | | 8b |
| 8c | Check CO and $CO_2$ amounts | | | | 8c |
| 9 | Check fuel-air adjustment at full fire | | | | |
| 9a | Set firing rate at 100% | | | | 9a |
| 9b | Perform flue gas analysis | | | | 9b |
| 9c | Check CO and $CO_2$ amounts | | | | 9c |

COMMENTS:______________________________

INSPECTION CHECK LIST CL 4A-1 -- BOILER (continued)

Page 5

Boiler no.__________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | **Boiler water level control and safety:** | | | | |
| 1 | Water level control and low water cutoff level | | | | 1 |
| 2 | Wiring connection, switch installed correctly | | | | 2 |
| 3 | Test actual operation: | | | | |
| 3a | Set burner in low fire | | | | 3a |
| 3b | Turn off makeup water valve | | | | 3b |
| 3c | Drain boiler water slowly | | | | 3c |
| 3d | observe water gauge glass, control action, and alarm | | | | 3d |
| 4 | Gauge glass and gasket integraty | | | | 4 |
| 5 | Gauge glass cleanliness | | | | 5 |
| 6 | Operation of gauge glass isolation and drain valves properly | | | | 6 |
| 7 | Operation of try-cocks properly | | | | 7 |
| | **Boiler breeching (for oil and gas boilers only):** | | | | |
| 1 | Pitch of breeching | | | | 1 |
| 2 | Cleanout door (location, size, latching, etc.) | | | | 2 |
| 3 | Expansion joint tightness | | | | 3 |
| 4 | Tightness of breeching entering chimney | | | | 4 |
| 5 | Test hole size and location | | | | 5 |
| 6 | Insulation thickness and integraty | | | | 6 |
| | **Oil preheating system (for No. 4, 5, and 6 oil only):** | | | | |
| 1 | Check piping arrangement against contract drawings | | | | 1 |
| 2 | Test electric heater thermostat | | | | 2 |
| 2a | Cutin temperature (* F) ____ F | | | | 2a |
| 2b | Cutout temperature (* F) ____ F | | | | 2b |
| 3 | Test hot water or steam heater thermostat | | | | 3 |
| 3a | Cutin temperature (* F) ____ F | | | | 3a |
| 3b | Cutout temperature (* F) ____ F | | | | 3b |
| 4 | Electric heater capacity | | | | 4 |
| 5 | Hot water or steam heater capacity | | | | 5 |
| 6 | Overall heater operation | | | | 6 |
| 7 | Steam trap operation | | | | 7 |

COMMENTS:____________________________________________

____________________________________________

____________________________________________

INSPECTION CHECK LIST CL 4A-1 -- BOILER (continued)

Page 6

Boiler no.________________ Date_________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | Soot blower (Oil fired steam boilers only): | | | | |
| 1 | Burner at full firing | | | | 1 |
| 2 | Open drain valve | | | | 2 |
| 3 | Open steam valve to warm piping | | | | 3 |
| 4 | Close drain valve | | | | 4 |
| 5 | Steam pressure at recommended level | | | | 5 |
| 6 | Perform soot blowing | | | | 6 |
| 7 | Close steam valve | | | | 7 |
| 8 | open drain valve | | | | 8 |
| 9 | Evaluate soot blowing operation | | | | 9 |

COMMENTS:______________________________________________

## 4.2 INSPECTION CHECK LIST CL 4A-2 -- FURNACE

Page 1

Furnace no.________________ Date__________
Make & model________________ Inspection agent_______________
Serial no.________________ Commissioning team_______________
Furnace type________________ _______________
Energy source: oil___ gas___ elec___ _______________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify furnace model with submittals | | | | 3 |
| 4 | Access space adequate | | | | 4 |
| 5 | Heating plant clean, no fire hazards | | | | 5 |
| 6 | Heating plant ventilation opening proper | | | | 6 |
| 7 | Pipe fittings and accessories complete | | | | 7 |
| 8 | Pipes not supported on furnace | | | | 8 |
| 9 | Flexible connection on duct installed | | | | 9 |
| 10 | Protection shields for motor and belts | | | | 10 |
| 11 | Alignment of motor and fan | | | | 11 |
| 12 | Belt tightness | | | | 12 |
| 13 | Lubrication complete and proper | | | | 13 |
| 14 | Thermal insulation complete and no damage | | | | 14 |
| 15 | Surface paint complete, equipment labels complete and legible | | | | 15 |
| 16 | Control wiring installed properly | | | | 16 |
| 17 | Mercury switchs and mercury type thermosta leveled correctly | | | | 17 |
| 18 | Power wiring installed properly | | | | 18 |
| 19 | All elec components grounded properly | | | | 19 |
| 20 | All electric connections tight | | | | 20 |
| 21 | Test run fan motor for direction of rotation | | | | 21 |
| 22 | Air filter clean | | | | 22 |
| 23 | Inspect oil nozzles, oil filter | | | | 23 |
| 24 | Gas pilot flame stable, when fan is on | | | | 24 |

COMMENTS:______________________________________________
______________________________________________
______________________________________________

INSPECTION CHECK LIST CL 4A-2 -- FURNACE (continued)

Page 2

Furnace No.________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 25 | Test control operation | | | | |
| 25a | Raise room thermostat setting 10 F above room temperature | | | | 25a |
| 25b | Observe burner operation | | | | 25b |
| 25c | Record bonnet tempertature when fan starts running ___ F | | | | 25c |
| 25d | Test limit switch and record temperature when burner stops ___ F | | | | 25d |
| 25e | Turn thermostat down 10 F or till burner stops | | | | 25e |
| 25f | Record bonnet temperature when fan stops ___ F | | | | 25f |
| 26 | No unusual noise & vibration when running | | | | 26 |

COMMENTS:____________________________________________

## 4.3 TEST WORK SHEET WS 4B-1 -- INSTRUMENT CALIBRATION FOR BOILER AND FURNACE

Page 1

Date__________
Test agent________________________
Commissioning team________________
________________
________________

Notes for using form:

1. This work sheet is used for calibrating sensing devices and instruments used in recording performance tests. Calibration of indicating devices for equipment operations are covered under equipment test work sheets.
2. Standard instruments used for calibrating sensing devices must have valid calibration. Record calibration data in Block A.
3. All instruments and sensing devices must be calibrated on bench or in field with standard instruments. At least two points covering the entire rangeofnormal operation should be calibrated. This work sheet lists recommended calibration points. After final calibration, record data in Block B.

A. Standard instruments data (copy from standard instrument records):

| | type | Make, model & serial no. | Calib. Date | Calib. by (organization) |
|---|---|---|---|---|
| Temperature | | | | |
| Humidity | | | | |
| Pressure | | | | |
| Power | | | | |
| Flow rate | | | | |
| Gas concentration | | | | |
| Others | | | | |

B. Final calibration data (calibration points listed below may be changed according to application):

| | | Low point | | | High point | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Instrument or sensing Device | Approx. Calib Point | Std Inst Reading | Final Calib Reading | Approx. Calib Point | Std Inst Reading | Final Calib Reading | No. |
| Temperature, F: | | | | | | | | |
| 1 | Water (for feed water, condensate, and hot water) | 32 | | | 200 | | | 1 |

TEST WORK SHEET WS 8B-1 -- INSTRUMENT CALIBRATION FOR BOILER AND FURNACE continued

Page 2

Date__________

| No. | Instrument or sensing Device | Low point: Approx. Calib Point | Low point: Std Inst Reading | Low point: Final Calib Reading | High point: Approx. Calib Point | High point: Std Inst Reading | High point: Final Calib Reading | No. |
|---|---|---|---|---|---|---|---|---|
| | Humidity: | | | | | | | |
| 2 | Relative humidity, % | 30#1 | | | 90#1 | | | 2 |
| 3 | Dew point temp, F | 35 | | | 75 | | | 3 |
| 4 | Wet bulb temp, F | 35#2 | | | 75#2 | | | 4 |
| 5 | Low pressure steam | 200 | | | 300 | | | 5 |
| 6 | Air | 32 | | | 150 | | | 6 |
| 7 | Flue | 300 | | | 2000 | | | 7 |
| | Flow: | | | | | | | |
| 8 | Water and steam, gpm | #3 | | | #4 | | | 8 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 9 | Fuel (gas/oil) | #5 | | | | | | 9 |
| | Pressure: | | | | | | | |
| 10 | Gas, in. w.c. | 0 | | | 20 | | | 10 |
| 11 | Steam, psia | 0 | | | 50 (for low pressure steam) | | | 11 |
| | Flue gas concentration | | | | | | | |
| 12 | CO2, % | 0 | | | 20 | | | 12 |
| 13 | O2, % | 0 | | | 20 | | | 13 |
| 14 | CO, % | 0 | | | 3 | | | 14 |
| | Other devices: | | | | | | | |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |

Notes:

#1 Within a dry bulb range of 10 - 100 F
#2 Within a dry bulb range of 35 - 100 F
#3 25% below specified values
#4 25% above specified values
#5 Check against a calibrated flow instrument

Comments:______________________________________________

## 4.4 TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER

Page 1

Boiler no.__________________ Date__________
Make & model________________ Inspection agent_________________

Serial no.__________________ Commissioning team_______________
Boiler type_________________
Heating medium: steam___ water___
Energy source: oil___ gas___
Pressure______ psig

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Test combustion efficiency at 25% capacity: | | | | 1 |
| 1a | After boiler is warmed up set capacity to approx. 25% and on manual control; adjust building load to match boiler capacity | | | | 1a |
| 1b | Capacity check by fuel input or heat output:<br>(a) Fuel input:<br>elapsed time ____ h<br>net gas meter reading ____ $ft^3$<br>net oil meter reading ____ gal<br>fuel input _____$ft^3$/h or gph<br>(b) Heat output:<br>measured heat output _____Btu/h<br>* Btu/h x 0.25 = ____Btu/h | | | | 1b |

COMMENTS:______________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 2

Boiler no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1c | Prove of steady state:<br><br>1 2 3<br>Flue temp ____,____,____ F<br>For hot water boiler:<br>ent water temp____,____,____ F<br>lvg water temp____,____,____ F<br>For steam boiler:<br>steam pressure____,____,____ psig<br>steam temp ____,____,____ F | | | | 1c |
| 1d | Check steam condition (steam boiler only for all 3 sets of steam readings. Steam must be at least saturated. | | | | 1d |
| 1e | Flue gas CO level____ % by vol<br>Specified max CO level * % by vol<br>If measured level is higher than specified, stop test | | | | 1e |
| 1f | Take data at 15 min intervals:<br><br>1 2 3<br>$CO_2$ or $O_2$ level ____,____,____ %<br>flue gas temp ____,____,____ F<br>comb air temp ____,____,____ F<br>For H W boiler:<br>ent water temp ____,____,____ F<br>lvg water temp ____,____,____ F or<br>water temp diff ____,____,____ F<br>For steam boiler:<br>steam pressure ____,____,____ psig<br>steam temp ____,____,____ F<br>feed water temp ____,____,____ F | | | | 1f |

COMMENTS:________________________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 3

Boiler no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1g | Average test data:<br>$CO_2$ or $O_2$ level ____ %<br>flue gas temp ____ F<br>comb air temp ____ F<br>For H W boiler:<br>ent water temp ____ F<br>lvg water temp ____ F or<br>water temp diff ____ F<br>For steam boiler:<br>steam pressure ____ psig<br>steam temp ____ F<br>feed water temp ____ F | | | | 1g |
| 2 | Test combustion efficiency at 50% capacity: | | | | 2 |
| 2a | Set capacity to approx. 50% and on manual control; adjust building load to match boiler capacity | | | | 2a |
| 2b | Capacity check by fuel input or heat output:<br>(a) Fuel input:<br>elapsed time ____ h<br>net gas meter reading ____ $ft^3$<br>net oil meter reading ____ gal<br>fuel input _____$ft^3/h$ or gph<br>* $ft^3/h$ or gph x 0.5 = ____<br>(b) Heat output:<br>measured heat output _____Btu/h<br>* Btu/h x 0.5 = ____Btu/h | | | | 2b |
| 2c | Prove of steady state:<br>1 2 3<br>Flue temp _____,_____,_____ F<br>For hot water boiler:<br>ent water temp____,____,____ F<br>lvg water temp____,____,____ F<br>For steam boiler:<br>steam pressure____,____,____ psig<br>steam temp ____,____,____ F | | | | 2c |

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 4

Boiler no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 2d | Check steam condition (steam boiler only for all 3 sets of steam readings. Steam must be at least saturated. | | | | 2d |
| 2e | Flue gas CO level____ % by vol<br>Specified max CO level * % by vol<br>If measured level is higher than specified, stop test | | | | 2e |
| 2f | Take data at 15 min intervals:<br>1 2 3<br>$CO_2$ or $O_2$ level ____,____,____ %<br>flue gas temp ____,____,____ F<br>comb air temp ____,____,____ F<br>For H W boiler:<br>ent water temp ____,____,____ F<br>lvg water temp ____,____,____ F or<br>water temp diff ____,____,____ F<br>For steam boiler:<br>steam pressure ____,____,____ psig<br>steam temp ____,____,____ F<br>feed water temp ____,____,____ F | | | | 2f |
| 2g | Average test data:<br>$CO_2$ or $O_2$ level ____ %<br>flue gas temp ____ F<br>comb air temp ____ F<br>For H W boiler:<br>ent water temp ____ F<br>lvg water temp ____ F or<br>water temp diff ____ F<br>For steam boiler:<br>steam pressure ____ psig<br>steam temp ____ F<br>feed water temp ____ F | | | | 2g |

COMMENTS:

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 5

Boiler no.________________ Date_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 3 Test combustion efficiency at 75% capacity: | | | | 3 |
| | 3a Set capacity to approx. 75% and on manual control; adjust building load to match boiler capacity | | | | 3a |
| | 3b Capacity check by fuel input or heat input:<br>(a) Fuel input:<br>elapsed time ___ h<br>net gas meter reading ___ $ft^3$<br>net oil meter reading ___ gal<br>* $ft^3$/h or gph x 0.75 = ____ Btu/h<br>(b) Heat output:<br>measured heat output ____ Btu/h<br>* Btu/h x 0.75 = ____ Btu/h | | | | 3b |
| | 3c Prove of steady state:<br>1 2 3<br>Flue temp<br>For hot water boiler:<br>ent water temp___,___,___ F<br>lvg water temp___,___,___ F<br>For steam boiler:<br>steam pressure___,___,___ psig<br>steam temp ___,___,___ F | | | | 3c |
| | 3d Check steam condition (steam boiler only for all 3 sets of steam readings. Steam must be at least saturated. | | | | 3d |
| | 3e Flue gas CO level____ % by vol<br>Specified max CO level * % by vol<br>If measured level is higher than specified, stop test | | | | 3e |

COMMENTS:______________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued



Boiler no.________________ Date_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 3f Take data at 15 min intervals: | | | | 3f |

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| $CO_2$ or $O_2$ level | ____, | ____, | ____ | % |
| flue gas temp | ____, | ____, | ____ | F |
| comb air temp | ____, | ____, | ____ | F |
| For H W boiler: | | | | |
| ent water temp | ____, | ____, | ____ | F |
| lvg water temp | ____, | ____, | ____ | F or |
| water temp diff | ____, | ____, | ____ | F |
| For steam boiler: | | | | |
| steam pressure | ____, | ____, | ____ | psig |
| steam temp | ____, | ____, | ____ | F |
| feed water temp | ____, | ____, | ____ | F |

3g Average test data: 3g

$CO_2$ or $O_2$ level ____ %
flue gas temp ____ F
comb air temp ____ F
For H W boiler:
ent water temp ____ F
lvg water temp ____ F or
water temp diff ____ F
For steam boiler:
steam pressure ____ psig
steam temp ____ F
feed water temp ____ F

4 Test boiler capacity and efficiency at 100% capacity: 4

4a Set capacity to full and on manual control; adjust building load to match boiler capacity 4a

COMMENTS:____________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 7

Boiler no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 4b | Prove of steady state:<br><br>1 2 3<br>Flue temp ____,____,____ F<br>For hot water boiler:<br>ent water temp____,____,____ F<br>lvg water temp____,____,____ F<br>For steam boiler:<br>steam pressure____,____,____ psig<br>steam temp ____,____,____ F | | | | 4b |
| 4c | Check steam condition (steam boiler only for all 3 sets of steam readings. Steam must be at least saturated. | | | | 4c |
| 4d | Flue gas CO level____ % by vol<br>Specified max CO level * % by vol<br>If measured level is higher than specified, stop test | | | | 4d |
| 4e | Take fuel data for test period:<br>elapsed time ____ h<br>For gas fired boiler:<br>barometric pressure ____ in. Hg<br>net gas meter reading ____ $ft^3$<br>gas pressure ____ in. wc<br>gas temp ____ F or<br>For oil fired boiler:<br>net oil meter reading ____ gal<br>oil pressure ____ psig<br>oil temp ____ F<br><br>Gas or oil flow rate:<br><br>$\frac{\text{meter reading}}{\text{time}} = \frac{\_\_\_\_}{\_\_\_\_} =$ ____ $ft^3/h$ or gph | | | | 4e |

COMMENTS:________________________________________

________________________________________

________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued



Boiler no.________________ Date_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

4f Take data at 15 min intervals: 4f

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| comb air temp | ____ | ____ | ____ | F |
| For H W boiler: | | | | |
| ent water temp | ____ | ____ | ____ | F |
| lvg water temp | ____ | ____ | ____ | F or |
| water temp diff | ____ | ____ | ____ | F |
| water flow rate | ____ | ____ | ____ | gpm |

location of flow measurement:
(check one) ent____, lvg____

| | | | | |
|---|---|---|---|---|
| For steam boiler: | | | | |
| steam pressure | ____ | ____ | ____ | psig |
| steam temp | ____ | ____ | ____ | F |
| feed water temp | ____ | ____ | ____ | F |

4g Average test data: 4g

comb air temp ____ F
For H W boiler:
ent water temp ____ F
lvg water temp ____ F or
water temp diff ____ F
water flow rate ____ gpm
For steam boiler:
steam pressure ____ psig
steam temp ____ F
feed water temp ____ F

5 Calculate capacity & performance: 5

5a Capacity: use 100% capacity test data 5a

(a) Hot water boiler:

If test data is in vol flow rate (Q gpm), convert to mass flow rate (M lb/h) by SE-13

Enthalpy of leaving water ($H_{out}$) _____ Btu/lb

Enthalpy of entering water ($H_{in}$) _____ Btu/lb

Test capacity $(CAP)_t = M \times (H_{out} - H_{in})$ Btu/h

= _____ x ( _____ - _____ ) = _____ Btu/h

COMMENTS:______________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 9

Boiler no.________________ Date_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

(b) Steam boiler:

If test data is in vol flow rate (Q), convert to mass flow rate (M lb/h) by using steam table

Enthalpy of steam ($H_s$) _____ Btu/lb

Enthalpy of feed water ($H_w$) _____ Btu/lb

Test capacity $(CAP)_t = M \times (H_s - H_w)$ Btu/h

= _____ x ( _____ - _____ ) = _____ Btu/h

5b Combustion efficiency at part load, use charts (see EXHIBIT 4-B) 5b

efficiency at 25% cap (25% eff) = _____ %

efficiency at 50% cap (50% eff) = _____ %

efficiency at 75% cap (75% eff) = _____ %

5c Thermal efficiency at full load: 5c

(a) Heat input for gas fired boiler:

Convert measured gas flow rate to that of standard conditions (equation in 7.2.1, EXHIBIT 4-B):

Flow rate at std conditions $Q_s$ = _____ $ft^3/h$

Heating value of gas (HHV) _____ $Btu/ft^3$

Calculate heat input of boiler:

$(q)_{in} = (Q_s) \times (HHV)$ = _____ X _____ = _____ Btu/h

(b) Heat input for oil fired boiler:

Calculate oil flow rate at 60 F (equation in 7.2.2, Exhibit 4-B):

Flow rate at 60 F = _____ gph

Heating value of oil (HHV) ______Btu/gal

Calculate heat input of boiler:

$(q)_{in} = (Q_s) \times (HHV)$ = _____ x_____ = _____ Btu/h

COMMENTS:_______________________________________________

_______________________________________________

_______________________________________________

TEST WORK SHEET WS 4B-2 -- GAS AND OIL FIRED BOILER continued

Page 10

Boiler no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | (c) Output of boiler: $(q)_{out} = (CAP)_t =$ _____ Btu/h (from 5a) | | | | |
| | (d) Boiler thermal efficiency: $eff = \frac{(q)_{out}}{(q)_{in}} \times 100 = \frac{\_\_\_\_\_}{\_\_\_\_\_} \times 100 =$ _____ % | | | | |
| 6. | Acceptance criteria:<br>Capacity: $(CAP)_t > (CAP)_s$<br>Combustion efficiency at part load:<br>at 25% capacity not less than * %<br>at 50% capacity not less than * %<br>at 75% capacity not less than * %<br>Thermal efficiency at full load no less than * % | | | | 6 |

COMMENTS:______________________________________________

______________________________________________

______________________________________________

## 4.5 TEST WORK SHEET WS 4B-3 -- ELECTRIC BOILER

Page 1

Boiler no._________________ Date__________
Make & model________________ Inspection agent_______________

Serial no._________________ Commissioning team_______________
Boiler type_________________
Heating medium: steam___ water___
Pressure______ psig

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Test boiler capacity and efficiency at 100% capacity: | | | | 1 |
| 1a | Set capacity to full and on manual control; adjust building load to match boiler capacity | | | | 1a |
| 1b | Check electric voltage:<br>phases 1-2 ____ V<br>phases 1-3 ____ V<br>phases 2-3 ____ V | | | | 1b |
| 1c | Prove of steady state:<br>1 2 3<br>ent water temp____,____,____HW boiler<br>lvg water temp____,____,____HW boiler<br>steam pressure____,____,____St boiler<br>steam temp ____,____,____ F | | | | 1c |
| 1d | Check steam condition (ST boiler only) for all 3 sets of steam readings. Steam must be at least saturated. | | | | 1d |

COMMENTS:__________________________________________________________

TEST WORK SHEET WS 4B-3 -- ELECTRIC BOILER continued

Page 2

Boiler no.________________ Date_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1e | Take data for test period:<br>time at start of test ____h____min____sec<br>watthour reading at beginning ____ Wh<br>time at end of test ____h____min____sec<br>watthour reading at end ____ Wh | | | | 1e |
| 1f | Take data at 15 min intervals:<br>1 2 3<br>room air temp ____,____,____ F<br>For H W boiler:<br>ent water temp ____,____,____ F<br>lvg water temp ____,____,____ F or<br>water temp diff ____,____,____ F<br>water flow rate ____,____,____ gpm<br>location of flow measurement:<br>(check one) ent____, lvg____<br>For steam boiler:<br>steam pressure ____,____,____ psig<br>steam temp ____,____,____ F<br>feed water temp ____,____,____ F<br>steam flow rate ____,____,____ $ft^3/min$ | | | | 1f |
| 1g | Average test data:<br>room air temp ____ F<br>For H W boiler:<br>ent water temp ____ F<br>lvg water temp ____ F or<br>water temp diff ____ F<br>water flow rate ____ gpm<br>For steam boiler:<br>steam pressure ____ psig<br>steam temp ____ F<br>feed water temp ____ F<br>steam flow rate ____ $ft^3/min$ | | | | 1g |

COMMENTS:_______________________________________________

TEST WORK SHEET WS 4B-3 -- ELECTRIC BOILER continued

Page 3

Boiler no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

2 Calculate capacity & performance: 2

2a Capacity: 2a

(a) Hot water boiler:

If test data is in vol flow rate (Q gpm), convert to mass flow rate (M lb/h) by SE-13

Enthalpy of leaving water ($H_{out}$) _____ Btu/lb

Enthalpy of entering water ($H_{in}$) _____ Btu/lb

Test capacity $(CAP)_t = M \times (H_{out} - H_{in})$ Btu/h

= _____ x ( _____ - _____ ) = _____ Btu/h

(b) Steam boiler:

If test data is in vol flow rate (Q), convert to mass flow rate (M lb/h) by using steam table

Enthalpy of steam ($H_s$) _____ Btu/lb

Enthalpy of feed water ($H_w$) _____ Btu/lb

Test capacity $(CAP)_t = M \times (H_s - H_w)$ Btu/h

= _____ x ( _____ - _____ ) = _____ Btu/h

2b Thermal efficiency at full load: 2b

(a) Heat input rate to boiler (see 1d):

$$(q)_{in} = \frac{(\text{end kwh} - \text{start kwh})}{(\text{end time} - \text{start time})}$$

$$= \frac{(\_\_\_\_\text{kwh}) - (\_\_\_\_\text{kwh})}{(\_\_\_\_\text{h}) - (\_\_\_\_\text{h})} \times 3413 = \_\_\_\_\_ \text{ Btu/h}$$

COMMENTS:______________________________________________

TEST WORK SHEET WS 4B-3 -- ELECTRIC BOILER continued

Page 4

Boiler no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

(b) Output of boiler:

$(q)_{out} = (CAP)_t =$ _____ Btu/h (from 2a)

(c) Boiler thermal efficiency:

$$eff = \frac{(q)_{out}}{(q)_{in}} \times 100 = \frac{\_\_\_\_\_}{\_\_\_\_\_} \times 100 = \_\_\_\_\_ \%$$

3. Acceptance criteria: 3

Capacity: $(CAP)_t > (CAP)_s$

Thermal efficiency at full load no less than * %

COMMENTS:________________________________________

## 4.6 TEST WORK SHEET WS 4C-1 -- GAS AND-OIL FIRED AIR FURNACE

Page 1

Furnace no.________________ Date__________

Make & model________________ Inspection agent_______________

Serial no.________________ Commissioning team_______________

Furnace type________________ _______________

Energy source: oil___ gas___

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Turn thermostat up 10 F to start furnace combustion. | | | | 1 |
| 2 | Test capacity and combustion efficiency: | | | | 2 |
| 2a | Run furnace for at least 15 minutes. | | | | 2a |
| 2b | Flue gas CO level____ % by vol<br>Specified max CO level * % by vol<br>If measured level is higher than specified, stop test | | | | 2b |
| 2c | Take 3 sets of data at 15 min intervals:<br>1 2 3<br>$CO_2$ or $O_2$ level ____,____,____ %<br>flue gas temp ____,____,____ F<br>comb air temp ____,____,____ F<br>return air temp ____,____,____ F #<br>supply air temp ____,____,____ F #<br>air flow rate ____,____,____ CFM #<br># Traverse of duct cross section is required for both temperature and air flow. Prepare data recording sheet for traverse data. See EXHIBIT 2-C for flow traverse procedures. | | | | 2c |
| 2d | Take data:<br>return or supply air humidity<br>____ % or ____ F dew point<br>barometric pressure ____ in. water | | | | 2d |

COMMENTS:________________________________________

_________________________________________________

TEST WORK SHEET WS 4C-1 -- GAS AND OIL FIRED AIR-FURNACE continued

Page 2

Furnace no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 2e | Average test data:<br>$CO_2$ or $O_2$ level ____ %<br>flue gas temp ____ F<br>comb air temp ____ F<br>return air temp ____ F<br>supply air temp ____ F<br>air flow rate ____ CFM | | | | 2e |
| 3 | Calculate capacity & performance: | | | | 3 |
| 3a | Capacity:<br>See EXHIBIT 2-B for calculation of air properties.<br>Calculate return air enthalpy (Hout) ____ Btu/lb<br>Calculate supply air enthalpy (Hout) ____ Btu/lb<br>Calculate specific volume of air (v), using average of supply and return air conditions:<br>average air temp ____F<br>average air humidity ____ % or ____ F dew point<br>average air density (v) ____ $lb/ft^3$<br>Measured air flow rate (Q), from 2e, ____ CFM<br>Calculate furnace capacity:<br>Test capacity $(CAP)_t = \frac{Q}{v} \times (H_{out} - H_{in})$ Btu/h<br>$= \frac{\_\_\_\_}{\_\_\_\_} \times (\_\_\_\_ - \_\_\_\_) = \_\_\_\_$ Btu/h | | | | 3a |
| 3b | Combustion efficiency at full load, use equations or charts (see Chapter 4)<br>combustion efficiency = ____ % | | | | 3b |
| 4 | Acceptance criteria:<br>Capacity: $(CAP)_t > (CAP)_s$<br>Combustion efficiency at full load not less than * % | | | | 4 |

COMMENTS:________________________________________

## 4.7 TEST WORK SHEET WS 4C-2 -- ELECTRIC AIR FURNACE

Page 1

Furnace no.________________ Date__________
Make & model________________ Inspection agent________________

Serial no.________________ Commissioning team________________
Furnace type________________ ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Check electric voltage:<br>phases 1-2 ____ V<br>phases 2-3 ____ V<br>phases 2-3 ____ V | | | | 1 |
| 2 | Turn thermostat up 10 F to start furnace combustion. | | | | 2 |
| 3 | Test capacity: | | | | 3 |
| 3a | Run furnace for at least 15 minutes. | | | | 3a |
| 3b | Take 3 sets of data at 15 min intervals:<br>1 2 3<br>return air temp ____,____,____ F #<br>supply air temp ____,____,____ F #<br>air flow rate ____,____,____ CFM #<br># Traverse of duct cross section is required for both temperature and air flow. Prepare data recording sheet for traverse data. See EXHIBIT 2-C for flow traverse procedures. | | | | 3b |
| 3c | Take other data:<br>return or supply air humidity<br>____ % or ____ F dew point<br>barometric pressure ____ in. water | | | | 3c |

COMMENTS:________________________________________________________
________________________________________________________
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TEST WORK SHEET WS 4C-2 -- ELECTRIC AIR FURNACE continued

Page 2

Furnace no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 3d | Average test data:<br>return air temp ____ F<br>supply air temp ____ F<br>air flow rate ____ CFM | | | | 3d |
| 4 | Calculate capacity & performance: | | | | 4 |
| 4a | Capacity:<br>See Chapter 2 for calculation of air properties.<br>Calculate return air enthalpy ($H_{out}$) ____ Btu/lb<br>Calculate supply air enthalpy ($H_{out}$) ____ Btu/lb<br>Calculate specific volume of air (v), using average of supply and return air conditions:<br>average air temp ____F<br>average air humidity ____ % or ____ F dew point<br>average air density (v) ____ lb/ft$^3$<br>Measured air flow rate (Q), from 2f, ____ CFM<br>Calculate furnace capacity:<br>Test capacity $(CAP)_t = \frac{Q}{v} \times (H_{out} - H_{in})$ Btu/h<br>$= \frac{\_\_\_\_}{\_\_\_\_} \times (\_\_\_\_ - \_\_\_\_) = \_\_\_\_$ Btu/h | | | | 4a |
| 4b | Combustion efficiency at full load, use equations or charts (see Chapter 4)<br>combustion efficiency = _____ % | | | | 4b |
| 5 | Acceptance criteria:<br>Capacity: $(CAP)_t > (CAP)_s$<br>Combustion efficiency at full load not less than * % | | | | 5 |

COMMENTS:________________________________________________

## 5.1 INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT

Page 1

ACU no.________________ Date__________
Make & model________________ Inspection agent________________

Serial no.________________ Commissioning team________________
Type________________ ________________
Heating medium: steam___ water___ ________________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| General: | | | | | |
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify unit model with submittals | | | | 3 |
| 4 | Tube pulling space adequate | | | | 4 |
| 5 | Air filter replacement space adequate | | | | 5 |
| 6 | Other access space adequate (headroom, access doors, etc) | | | | 6 |
| 7 | Equipement room cleaned, no fire hazards | | | | 7 |
| 8 | Equipment room ventilation opening proper | | | | 8 |
| 9 | Ventilation opening automatic damper | | | | 9 |
| 10 | Proper vibration unit installation | | | | 10 |
| 11 | Pipe fittings and accessories complete | | | | 11 |
| 12 | Check valves and flow switches flow direction correct | | | | 12 |
| 13 | Pipes supported properly | | | | 13 |
| 14 | Protection shields for motor and belts | | | | 14 |
| 15 | Alignment of motor driven components | | | | 15 |
| 16 | Belt tightness | | | | 16 |
| 17 | Lubrication complete and proper | | | | 17 |
| 18 | Thermometers complete | | | | 18 |
| 19 | Pressure gages complete | | | | 19 |
| 20 | Flow meters meet installation requirements | | | | 20 |
| 21 | Electric wiring installation proper | | | | 21 |
| 22 | Elec motors & components grounded properly | | | | 22 |
| 23 | All electric connections tight | | | | 23 |
| 24 | Size of overcurrent heater in motor starter | | | | 24 |
| 25 | Test run motors for direction of rotation | | | | 25 |
| 26 | Thermal insulation complete and no damage | | | | 26 |
| 27 | Surface paint complete, equipment labels complete and legible | | | | 27 |

COMMENTS:________________________________________________
________________________________________________
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INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT (continued)

Page 2

ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 28 | Control air pressure correct (compressed air control) | | | | 28 |
| 29 | No excessive air leakage of unit | | | | 29 |
| 30 | No unusual noise & vibration when running | | | | 30 |
| 31 | Automatic control instruments installed as specified | | | | 31 |
| 32 | Proper calibration of instrumentation | | | | 32 |
| | **Fan:** | | | | |
| 1 | Housing access doors and latchs tight | | | | 1 |
| 2 | Assembly bolts tight (field assembled fan) | | | | 2 |
| 3 | Grease or oil tubes for bearins proper | | | | 3 |
| 4 | No need removing belt guard for oiling or speed check | | | | 4 |
| 5 | Fan running steadily | | | | 5 |
| 6 | Fans with inlet vanes or outlet dampers: | | | | |
| 6a | Damper linkage no excessive play | | | | 6a |
| 6b | Damper closes tight | | | | 6b |
| 6c | Direction of inlet damper blade proper | | | | 6c |
| 6d | Inlet dampers for double inlet fan proper | | | | 6d |
| 7 | Protective hood over motor and belt for outdoor installation | | | | 7 |
| 8 | Inlet and outlet wire protection for fan without duct connection | | | | 8 |
| 9 | Flexible connections between fan and ducts | | | | 9 |
| 10 | Curb watertightness (power roof vent) | | | | 10 |

COMMENTS:______________________________________________________________

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INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT (continued)

Page 3

ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| Coils: | | | | | |
| 1 | No damage to heat transfer fins | | | | 1 |
| 1a | Preheat coil | | | | 1a |
| 1b | Main heating coil | | | | 1b |
| 1c | Precooling coil | | | | 1c |
| 1d | Main cooling coil | | | | 1d |
| 1e | Reheat coil | | | | 1e |
| 2 | Coil tubes pitch correctly | | | | 2 |
| 2a | Preheat coil | | | | 2a |
| 2b | Main heating coil | | | | 2b |
| 2c | Precooling coil | | | | 2c |
| 2d | Main cooling coil | | | | 2d |
| 2e | Reheat coil | | | | 2e |
| 3 | No air bypass between coil and casing | | | | 3 |
| 3a | Preheat coil | | | | 3a |
| 3b | Main heating coil | | | | 3b |
| 3c | Precooling coil | | | | 3c |
| 3d | Main cooling coil | | | | 3d |
| 3e | Reheat coil | | | | 3e |
| 4 | Cooilin coil drain pans and pipes | | | | 4 |
| 5 | Coil pipe fittings and accessories | | | | 5 |
| 5a | Shut-off valves | | | | 5a |
| 5b | Strainers | | | | 5b |
| 5c | Air vents | | | | 5c |
| 5d | Thermometer wells | | | | 5d |
| 5e | Balancing devices | | | | 5e |
| 5f | Drain | | | | 5f |
| 5g | Others | | | | 5g |
| 6 | Flow measuring device | | | | 6 |
| 6a | Upstream pipe length or flow straightener | | | | 6a |
| 6b | Downstream pipe length | | | | 6b |
| 6c | Meter connection and valves complete | | | | 6c |
| 6d | Tag with flow rate information | | | | 6d |
| 7 | Condensate pipe at steam trap - check that steam trap is not passing steam when control valve is open (for low pressure steam only) | | | | 7 |

COMMENTS:______________________________________________

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INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT (continued)

Page 4

AHU no.______________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | **Air filters:** | | | | |
| 1 | Filter frame anchored to casing securely | | | | 1 |
| 2 | No air leakage around filter frame | | | | 2 |
| 3 | No air leakage between filter bank and unit casing | | | | 3 |
| 4 | New filter media | | | | 4 |
| 5 | Filter gage pressure sensing tip proper | | | | 5 |
| 6 | Inclined manometer gage installation | | | | 6 |
| 7 | Check auto renewable filter advancing mechanism | | | | 7 |
| 7a | Motor | | | | 7a |
| 7b | Drivingtrain | | | | 7b |
| 7c | Timer | | | | 7c |
| 7d | Pressure sensing | | | | 7d |
| 7e | Overriding operation | | | | 7e |
| 8 | Filter replacement spece adequate | | | | 8 |
| 9 | Spare filters | | | | 9 |
| | **Air dampers:** | | | | |
| 1 | Blade arrangement: parallel_____ opposed _____ | | | | 1 |
| 2 | Blade edge sealing | | | | 2 |
| 3 | Bearings as specified | | | | 3 |
| 4 | Actuator linkage and blade movement | | | | 4 |
| 5 | Access door for dampers in duct | | | | 5 |
| | **Air louvers:** | | | | |
| 1 | Material | | | | 1 |
| 2 | Construction | | | | 2 |
| 3 | Dimensions | | | | 3 |
| 4 | Screen | | | | 4 |

COMMENTS:______________________________________________________________

INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT (continued)

Page 5

AHU no.__________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| Casings: | | | | | |
| 1 | Rigidity | | | | 1 |
| 2 | Integraty | | | | 2 |
| 3 | Access doors: | | | | 3 |
| 3a | Size | | | | 3a |
| 3b | Gasket | | | | 3b |
| 3c | latches | | | | 3c |
| 4 | Flexible connections between unit and ducts | | | | 4 |
| 5 | Outdoor unit roof curb flashing | | | | 5 |
| 6 | Enclosure for outdoor unit | | | | 6 |
| Thermal insulation: | | | | | |
| 1 | No damages and omissions | | | | 1 |
| 2 | Material | | | | 2 |
| 3 | Thickness | | | | 3 |
| 4 | Method of application | | | | 4 |
| 5 | Vapor barrier material and sealing | | | | 5 |
| 6 | Surface finishing | | | | 6 |

COMMENTS:________________________________________

INSPECTION CHECK LIST WS 5A-1 -- AIR HANDLING UNIT (continued)

Page 6

AHU no.____________________ Date___________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | **Automatic controls:** | | | | |
| 1 | Give general check on control installations against contract documemts and submittals, control diagrams complete, framed and mounted | | | | 1 |
| 2 | Observe general operation. Any obvious malfunction, incorrect calibrations, or incorrct settings and ranges? Hunting observed? | | | | 2 |
| 3 | Are mercury switches leveled correctly? | | | | 3 |
| 4 | Check valves for correct closing | | | | 4 |
| 5 | Valves and linkages installed securely | | | | 5 |
| 6 | Valve linkages travel freely | | | | 6 |
| 7 | Check dampers for correct closing | | | | 7 |
| 8 | Dampers and linkages installed securely | | | | 8 |
| 9 | Damper linkages travel freely | | | | 9 |
| 10 | Safety features (coil freeze trotection, etc.) installed correctly | | | | 10 |
| 11 | Interlocking installed correctly | | | | 11 |
| 12 | For pneumatic systems: | | | | 12 |
| 12a | Compressor intake filter clean | | | | 12a |
| 12b | Compressor discharge filter clean | | | | 12b |
| 12c | Compressor motor alignment | | | | 12c |
| 12d | Compressor belt tightness | | | | 12d |
| 12e | Belt protective shield | | | | 12e |
| 12f | Compressor oil level | | | | 12f |
| 12g | Compressor oil filter clean | | | | 12g |
| 12h | Air tank drain | | | | 12h |
| 12i | Air pressure at air tank | | | | 12i |
| 12j | Air pressure after pressure reducing valves | | | | 12j |
| 12k | Air tubing connections tight | | | | 12k |
| 12l | Air pressure gages | | | | |
| 13 | For electrcal and electronic systems: | | | | 13 |
| 13a | Wire connections tight | | | | 13a |
| 13b | No broken wires | | | | 13b |
| 13c | No rust on wire terminals | | | | 13c |
| 13d | Correct voltage of power supply | | | | 13d |
| 13e | Signal wires shielded correctly | | | | 13e |
| 14 | Control panels: wires and tubes labeled, settings marked, notes attached | | | | |

COMMENTS:________________________________________________________________

______________________________________________________________________

______________________________________________________________________

## 5.2 TEST WORK SHEET WS 5B-1 -- INSTRUMENT CALIBRATION FOR AIR HANDLING SYSTEMS

Page 1

Date__________
Test agent________________________
Commissioning team________________
________________
________________

Notes for using form:

1. This work sheet is used for calibrating sensing devices and instruments used in recording performance tests. Calibration of indicating devices for equipment operations are covered under equipment test work sheets.
2. Standard instruments used for calibrating sensing devices must have valid calibration. Record calibration data in Block A.
3. All instruments and sensing devices must be calibrated on bench or in field with standard instruments. At least two points covering the entire rangeofnormal operation should be calibrated. This work sheet lists recommended calibration points. After final calibration, record data in Block B.

A. Standard instruments data (copy from standard instrument records):

| | type | Make, model & serial no. | Calib. Date | Calib. by (organization) |
|---|---|---|---|---|
| Temperature | | | | |
| Humidity | | | | |
| Pressure | | | | |
| Power | | | | |
| Others | | | | |

B. Final calibration data (set-temperature listed below may be changed according to application):

| | | Low point | | | High point | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Instrument or sensing Device | Approx. Calib Point | Std Inst Reading | Final Calib Reading | Approx. Calib Point | Std Inst Reading | Final Calib Reading | No. |
| Temperature, F: | | | | | | | | |
| 1 | Water (for chilled, condenser, steam condensate, and hot) | 32 | | | 200 | | | 1 |
| 2 | Low pressure steam | 200 | | | 300 | | | 2 |
| 3 | Air | 32 | | | 150 | | | 3 |

TEST WORK SHEET WS 5B-1 -- INSTRUMENT CALIBRATION FOR AIR HANDLING SYSTEMS continued



Date__________

| No. | Instrument or sensing Device | Low point: Approx. Calib Point | Low point: Std Inst Reading | Low point: Final Calib Reading | High point: Approx. Calib Point | High point: Std Inst Reading | High point: Final Calib Reading | No. |
|---|---|---|---|---|---|---|---|---|
| | **Humidity:** | | | | | | | |
| 4 | Relative humidity, % see Note #1 | 30#1 | | | 90#1 | | | 4 |
| 5 | Dew point temp, F | 35 | | | 75 | | | 5 |
| 6 | Wet bulb temp, F see Note #2 | 35#2 | | | 75#2 | | | 6 |
| | **Flow:** | | | | | | | |
| 7 | Water and steam, gpm | #3 | | | #4 | | | 7 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 8 | Air velocity, fpm, Also see #5 | 0 | | | 1000 | | | 8 |
| | **Pressure:** | | | | | | | |
| 9 | Water, ft w.c. or psi | 0 | | | #6 | | | 9 |
| 10 | Air, in. w.c. | 0 | | | #7 | | | 10 |
| | **Other devices:** | | | | | | | |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |

Notes:

- #1 Within a dry bulb temperature range of 10 - 100 F
- #2 Within a dry bulb temperature range of 35 - 100 F
- #3 25% below specified values
- #4 25% above specified values
- #5 This is for velocity type instrumsnts, see pressure calibration for pressure sensing devices (pitot)
- #6 Expected highest pressure
- #7 Expected highest pressure or 5 in. w.c. whicherever is higher

Comments:______________________________________________

________________________________________________________

________________________________________________________

## 5.3 TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN

Page 1

AH (or fan) no.__________ Date________
Make & model__________ Inspection agent________

Serial no.__________ Commissioning team________
Type__________ ________
Fan type __________ ________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Supply air fan and return air fan for constant air volume system: | | | | |
| 1 | Set and lock outside air damper at minimum position | | | | 1 |
| 2 | Set and lock return air damper | | | | 2 |
| 3 | Set and lock relief air damper | | | | 3 |
| 4 | Measure barometric pressure _____ in.Hg | | | | 4 |
| 5 | Measure electric service voltage: | | | | 5 |
| 5a | Supply fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5a |
| 5b | Return fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5b |

COMMENTS:______________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 2

AH (or fan) no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6 | Measure supply air fan performance: | | | | 6 |
| 6a | Air flow rate, use Test Work Sheet WS 2C-1 or 2C-2 _____cfm (*_____cfm) | | | | 6a |
| 6b | Total p at fan inlet_____ in.w.c. | | | | 6b |
| 6c | Static p at fan inlet_____in.w.c. | | | | 6c |
| 6d | Total p at fan outlet_____in.w.c. | | | | 6d |
| 6e | Static p at fan outlet_____in.w.c. | | | | 6e |
| 6f | Velocity p at fan inlet_____in.w.c. | | | | 6f |
| 6g | Velocity p at fan outlet_____in.w.c. | | | | 6g |
| 6h | Fan speed _____ rpm | | | | 6h |
| 6i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 6i |
| 7 | Check 10% of supply air outlets: | | | | 7 |
| 7a | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 7a |
| 7b | Calculate error<br>(1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 7b |
| 7c | If 10% of 7b is outside +/- 10%, check another 10% of supply outlets: | | | | 7c |

COMMENTS:______________________________________________
______________________________________________
______________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 3

AH (or fan) no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7d | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 7d |
| 7e | Calculate error<br>(1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 7e |
| 8 | If 10% of the outlets measured in 7b & 7e are outside +/- 15%, rebalance system. | | | | 8 |
| 9 | Total air flow rate of measured outlets______cfm (7a & 7d) | | | | 9 |
| 10 | Total air flow rate of specified_______cfm (7a & 7d) | | | | 10 |
| 11 | Calculate error<br>(1 - measured/specified supply) x 100% = _____% | | | | 11 |
| 12 | If error in 11 is outside +/- 10%, rebalance system. | | | | 12 |
| 13 | Measure return air fan performance: | | | | 13 |
| 13a | Air flow rate, use Test Work Sheet WS 2C-1 or 2C-2 _____cfm (*_____cfm) | | | | 13a |
| 13b | Total p at fan inlet_____ in.w.c. | | | | 13b |
| 13c | Static p at fan inlet_____in.w.c. | | | | 13c |
| 13d | Total p at fan outlet_____in.w.c. | | | | 13d |
| 13e | Static p at fan outlet_____in.w.c. | | | | 13e |
| 13f | Velocity p at fan inlet_____in.w.c. | | | | 13f |
| 13g | Velocity p at fan outlet_____in.w.c. | | | | 13g |
| 13h | Fan speed _____ rpm | | | | 13h |

COMMENTS:______________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 4

AH (or fan) no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13i | Motor current and name plate FL current: | | | | 13i |
| | Lead 1 _____amp (* amp) | | | | |
| | Lead 2 _____amp (* amp) | | | | |
| | Lead 3 _____amp (* amp) | | | | |
| 14 | Set outside air damper to 100% OA | | | | 14 |
| 15 | Set return air damper | | | | 15 |
| 16 | Set relief air damper | | | | 16 |
| 17 | Measure supply fan motor current: | | | | 17 |
| | Lead 1 _____amp (* amp) | | | | |
| | Lead 2 _____amp (* amp) | | | | |
| | Lead 3 _____amp (* amp) | | | | |
| 18 | Measure return fan motor current: | | | | 18 |
| | Lead 1 _____amp (* amp) | | | | |
| | Lead 2 _____amp (* amp) | | | | |
| | Lead 3 _____amp (* amp) | | | | |
| 19 | Restore damper controls | | | | 19 |
| 20 | Check 10% of return air outlets: | | | | 20 |
| 20a | Room_____, measured _____cfm (* cfm) | | | | 20a |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| 20b | Calculate error | | | | 20b |
| | (1 - measured/specified supply) x 100% | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |

COMMENTS:____________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 5

AH (or fan) no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 20c | If 10% of 7b is outside +/- 10%, check another 10% of supply outlets: | | | | 20c |
| 20d | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 20d |
| 20e | Calculate error<br>(1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 20e |
| 21 | If 10% of the outlets measured in 7b & 7e are outside +/- 15%, rebalance system. | | | | 21 |
| 22 | Total air flow rate of measured outlets______cfm (7a & 7d) | | | | 22 |
| 23 | Total air flow rate of specified_______cfm (7a & 7d) | | | | 23 |
| 24 | Calculate error<br>(1 - measured/specified supply) x 100% = _____% | | | | 24 |
| 25 | If error in 11 is outside +/- 10%, rebalance system. | | | | 25 |

COMMENTS:____________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 6

AH (or fan) no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Supply air fan and return air fan for variable air volume system: | | | | |
| 1 | Set and lock outside air damper at 100% OA position | | | | 1 |
| 2 | Set and lock return air damper | | | | 2 |
| 3 | Set and lock relief air damper | | | | 3 |
| 4 | Measure barometric pressure _____ in.Hg | | | | 4 |
| 5 | Measure electric service voltage: | | | | 5 |
| 5a | Supply fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5a |
| 5b | Return fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5b |
| 6 | Select 10% of VAV boxes: | | | | |
| 6a | Lower rm. thermostats 5 F to measure max. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 6a |
| 6b | Raise rm. thermostats 10 F to measure min. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 6b |

COMMENTS:________________________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 7

AH (or fan) no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6c | Calculate error:<br>(1 - measured/specified supply) x 100%<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min) | | | | 6c |
| 7 | If 10% of VAV boxes measured are outside +/- 10%, check another 10% of boxes: | | | | |
| 7a | Lower rm. thermostats 5 F to measure max. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 7a |
| 7b | Raise rm. thermostats 10 F to measure min. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 7b |
| 7c | Calculate error:<br>(1 - measured/specified supply) x 100%<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min) | | | | 7c |

COMMENTS:____________________________________________________________
______________________________________________________________
______________________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 8

AH (or fan) no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | If 10% of the VAV boxes measured in 6 & 7 are outside +/- 15%, rebalance system. | | | | 8 |
| 9 | Total air flow rate of measured boxes_____cfm (max) | | | | 9 |
| 10 | Total air flow rate of specified______cfm (max) | | | | 10 |
| 11 | Total air flow rate of measured boxes_____cfm (min) | | | | 11 |
| 12 | Total air flow rate of specified______cfm (min) | | | | 12 |
| 13 | Calculate error:<br>(1 - measured/specified supply) x 100% = __% (max)<br>(1 - measured/specified supply) x 100% = __% (min) | | | | 13 |
| 14 | If error in 13 is outside +/- 10%, rebalance system. | | | | 14 |
| 15 | Measure and record duct static pressure at fan static pressure sensor locations:<br>Sensor #1 measured _____"w.c. (shown on control dwg _____"w.c.)<br>Sensor #2 measured _____"w.c. (shown on control dwg _____"w.c.)<br>Sensor #3 measured _____"w.c. (shown on control dwg _____"w.c.) | | | | 15 |
| 16 | Measure duct static pressure at branch ducts before last VAV boxes:<br>Branch 1 measured _____"w.c.<br>Branch 2 measured _____"w.c.<br>Branch 3 measured _____"w.c.<br>Branch 4 measured _____"w.c.<br>Branch 5 measured _____"w.c. | | | | 16 |
| 17 | Specified minimum static pressure *_____"w.c. | | | | 17 |
| 18 | Any branch must be:<br>*_____w.c. < measured press < measured press + 0.2"w.c. | | | | 18 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), FAN continued
Page 9

AH (or fan) no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 19 | Record supply air fan performance: | | | | 19 |
| 19a | Air flow rate, see Test Work Sheet WS 2C-1 or 2C-2 _____cfm (*_____cfm) | | | | 19a |
| 19b | Total p at fan inlet_____ in.w.c. | | | | 19b |
| 19c | Static p at fan inlet_____in.w.c. | | | | 19c |
| 19d | Total p at fan outlet_____in.w.c. | | | | 19d |
| 19e | Static p at fan outlet_____in.w.c. | | | | 19e |
| 19f | Velocity p at fan inlet_____in.w.c. | | | | 19f |
| 19g | Velocity p at fan outlet_____in.w.c. | | | | 19g |
| 19h | Fan speed _____ rpm | | | | 19h |
| 19i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 19i |
| 20 | Measure return air fan performance: | | | | 20 |
| 20a | Air flow rate, see Test Work Sheet WS 2C-1 or 2C-2 _____cfm (*_____cfm) | | | | 20a |
| 20b | Total p at fan inlet_____ in.w.c. | | | | 20b |
| 20c | Static p at fan inlet_____in.w.c. | | | | 20c |
| 20d | Total p at fan outlet_____in.w.c. | | | | 20d |
| 20e | Static p at fan outlet_____in.w.c. | | | | 20e |
| 20f | Velocity p at fan inlet_____in.w.c. | | | | 20f |
| 20g | Velocity p at fan outlet_____in.w.c. | | | | 20g |
| 20h | Fan speed _____ rpm | | | | 20h |
| 20i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 20i |
| 21 | Restore damper controls | | | | 21 |

COMMENTS:____________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HEATING COIL continued



AH no.__________________ Date__________

Preheat coil no.________ Inspection agent_________________

Reheat coil no.________ Commissioning team_______________

Heating medium: Steam___

(Check one) Water___

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.
3. All air temperature for coils must be measured at 1 ft sq face area

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Heating coil: | | | | |
| 1 | Measure coil air flow rate, see Test Work Sheet WS 2C-2 _____ cfm | | | | 1 |
| 2 | Measure entering air temp apply false load if needed (*_____ F) average temp _____ F | | | | 2 |
| 3 | Measure & adjust ent w temp to within 1 F of specified (water coil) (*_____ F) _____ F | | | | 3 |
| 4 | Measure & adjust steam temp & pressure (steam coil) to within 1 psi of specified (*_____ psi) _____ psi _____ F Is steam saturated? | | | | 4 |
| 5 | Measure and adjust water or steam flow rate to within 3% of specified | | | | 5 |
| 6 | Disable control of test coil | | | | 6 |
| 7 | Run unit for at least 10 minutes | | | | 7 |
| 8 | Test for steady state at 5 minute intervals: (max diff 2 F) average lvg air temp: _____,_____,_____ F | | | | 8 |
| 9 | Measure barometric pressure _____ in.Hg | | | | 9 |

COMMENTS:______________________________________________________________

_______________________________________________________________________

_______________________________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HEATING COIL continued

Page 11

AH no.________________

Date__________

Preheat coil no. _______

Reheat coil no. _______

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 10 | Measure and record 3 sets of test data at 5 min intervals: | | | | 10 |

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| Ent air temp | _____ | _____ | _____ | F |
| Lvg air temp | _____ | _____ | _____ | F |
| Ent w pressure | _____ | _____ | _____ | ft w.c. |
| Lvg w pressure | _____ | _____ | _____ | ft w.c. |
| Air friction | _____ | _____ | _____ | in.w.c. |

11 Calculate coil capacity: 11

11a Saturated water vapor, $P_{sw}$: 11a

$$P_{sw} = e^{(15.4638 - [7284/(Td+392)]}$$

$$(P_{sw})_{ent} = e^{(15.4638 - [7284/(\_\_\_\_\_+392)]} = \_\_\_\_\_ \text{ in. Hg}$$

11b Vapor pressure, $P_w$: 11b

$$P_w = RH \times P_{sw}$$

$$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

COMMENTS:________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HEATING COIL continued



AH no._______________ Date_________
Preheat coil no. ______
Reheat coil no. ______

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

11c Humidity ratio, W: 11c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$$(W)_{ent} = 0.622 \times \frac{\_\_\_\_}{\_\_\_\_ - \_\_\_\_} = \_\_\_\_ \text{ lb vapor/lb dry air}$$

$$(W)_{ent} = (W)_{ent} = \_\_\_\_ \text{ lb vapor/lb dry air}$$

11d Enthalpy, H: 11d

$$H = 0.24 \times Td + W\ (1061 + 0.444 \times Td)$$

$$(H)_{ent} = 0.24 \times \_\_\_\_ + \_\_\_\_\ (1061 + 0.444 \times \_\_\_\_) = \_\_\_\_ \text{ Btu/lb}$$

$$(H)_{lvg} = 0.24 \times \_\_\_\_ + \_\_\_\_\ (1061 + 0.444 \times \_\_\_\_) = \_\_\_\_ \text{ Btu/lb}$$

11e Specific volume of air, v: 11e

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b}(1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_ + 460)}{P_b}(1 + 1.6078 \times W) = \_\_\_\_ \text{ cu ft/lb}$$

COMMENTS:________________________________________
________________________________________________
________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HEATING COIL continued

Page 13

AH no.________ Date________

Preheat coil no. ________

Reheat coil no. ________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 11f | Mass flow rate of air, M: | | | | 11f |

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_\_} = \_\_\_\_\_ \text{ lb/min}$$

11g Coil heating capacity, C: 11g

$$C = 60\ M \times [(H)_{lvg} - (H)_{ent}]$$

$$= 60 \times \_\_\_\_\_ \times (\_\_\_\_\_ - \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/h}$$

12 Repeat calculations for all 3 sets of data, Averaged coil heating capacity: 12

$$(\_\_\_\_\_ + \_\_\_\_\_ + \_\_\_\_\_)/3 = \_\_\_\_\_ \text{ Btu/h}$$

13 Calculate coil water pressure drop, P: 13

$$P = (P)_{ent} - (P)_{lvg} = \_\_\_\_\_ - \_\_\_\_\_ = \_\_\_\_\_ \text{ ft w.c.}$$

14 Acceptance criteria: 14

C > 0.95 x * capacity > 0.95 x _____ > _____

P < 1.1 x * press drop < 1.1 x _____ < _____

AF < 1.1 x * air friction < 1.1 x _____ < _____

COMMENTS: ____________________________________________

____________________________________________

____________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), COOLING COIL continued

Page 14

AH no.________________ Date__________

Precooling coil no._____ Inspection agent________________

Cooling coil no.________ Commissioning team______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.
3. All air temperature for coils must be measured at 1 ft sq face area and averaged.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Water coil: | | | | |
| 1 | Measure coil air flow rate, see Test Work Sheet WS 2C-2 _____ cfm | | | | 1 |
| 2 | Measure entering air temp & humidity; apply false load if needed (*_____ F, *_____ % RH) average temp _____ F, _____ % RH | | | | 2 |
| 3 | Measure & adjust ent w temp to within 1 F of specified (water coil) (*_____ F) _____ F | | | | 3 |
| 4 | Measure and adjust water flow rate to within 3% of specified | | | | 4 |
| 5 | Disable control of test coil | | | | 5 |
| 6 | Run unit for at least 10 minutes | | | | 6 |
| 7 | Test for steady state at 5 minute intervals: (max diff 2 F) Average lvg air temp: _____,_____,_____ F Leaving air humidity: _____,_____,_____ % RH | | | | 7 |

COMMENTS:________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), COOLING COIL continued

Page 15

AH no.________________ Date__________

Precooling coil no. ____

Cooling coil no. ______

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | Measure barometric pressure _____ in.Hg | | | | 8 |
| 9 | Measure and record 3 sets of test data at 10 min intervals: | | | | 9 |

1 2 3

Ent air temp _____,_____,_____ F

Lvg air temp _____,_____,_____ F

Ent air humidity _____,_____,_____ %

Lvg air humidity _____,_____,_____ %

Ent w pressure _____,_____,_____ ft w.c. (coil or condenser)

Lvg w pressure _____,_____,_____ ft w.c. (coil or condenser)

Air friction _____,_____,_____ in.w.c.

10 Average test data: 10

Ent w pressure, (p)ent _____ ft w.c. (coil or condenser)

Lvg w pressure, (P)lvg _____ ft w.c. (coil or condenser)

Air friction, AF _____ in.w.c.

11 Calculate coil capacity: 11

11a Saturated water vapor of air, $P_{sw}$: 11a

$$P_{sw} = e^{(15.4638 - [7284/(Td-392)]}$$

$$(P_{sw})_{ent} = e^{(15.4638 - [7284/\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

$$(P_{sw})_{lvg} = e^{(15.4638 - [7284/\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

COMMENTS:______________________________________________

____________________________________________________

____________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), COOLING COIL continued

Page 16

AH no.________________ Date__________
Precooling coil no. ____
Cooling coil no. _______

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

11b Vapor pressure, $P_w$: 11b

$$P_w = RH \times P_{sw}$$

$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times$ _____ = _____ in.Hg

$(P_w)_{ent} = 0.5 \times (P_{sw})_{lvg} = 0.5 \times$ _____ = _____ in.Hg

11c Humidity ratio, W: 11c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$(W)_{ent} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} =$ _____ lb vapor/lb dry air

$(W)_{lvg} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} =$ _____ lb vapor/lb dry air

11d Enthalpy, H: 11d

$$H = 0.24 \times Td + W\ (1061 + 0.444 \times Td)$$

$(H)_{ent} = 0.24 \times$ _____ + _____ (1061 + 0.444 x _____) = _____ Btu/lb

$(H)_{lvg} = 0.24 \times$ _____ + _____ (1061 + 0.444 x _____) = _____ Btu/lb

COMMENTS:______________________________________________
________________________________________________
________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), COOLING COIL continued
Page 17

AH no.__________________ Date__________
Precooling coil no. ____
Cooling coil no. _______

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

11e Specific volume of air, v: 11e

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b} (1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_\_ + 460)}{P_b} (1 + 1.6078 \times W) = \_\_\_\_\_ \text{ cu ft/lb}$$

11f Mass flow rate of air, M: 11f

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_\_} = \_\_\_\_\_ \text{ lb/min}$$

11g Coil cooling capacity, C: 11g

$$C = 60\ M \times [(H)_{lvg} - (H)_{ent}]$$

$$= 60 \times \_\_\_\_\_ \times (\_\_\_\_\_ - \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/h}$$

12 Repeat calculations for all 3 sets of data,
Averaged coil heating capacity: 12

$$(\_\_\_\_\_ + \_\_\_\_\_ + \_\_\_\_\_)/3 = \_\_\_\_\_ \text{ Btu/h}$$

13 Calculate coil or condenser pressure drop, P: 13

$$P = (P)_{ent} - (P)_{lvg} = \_\_\_\_\_ - \_\_\_\_\_ = \_\_\_\_\_ \text{ ft w.c.}$$

14 Acceptance criteria: 14

$C > 0.95 \times *$ capacity $> 0.95 \times \_\_\_\_\_ > \_\_\_\_\_$
$P < 1.1 \times *$ press drop $< 1.1 \times \_\_\_\_\_ < \_\_\_\_\_$ (coil or condenser)
$AF < 1.1 \times *$ air friction $< 1.1 \times \_\_\_\_\_ < \_\_\_\_\_$

COMMENTS:______________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HUMIDIFIER
Page 18

AH no.____________ Date_________
Humidifier no. ____________ Inspection agent________________

Make and model ____________ Commissioning team______________
Serial no.________________ ______________
Type ______________________ ______________

Notes for using form:
1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Measure coil air flow rate, see Test Work Sheet WS 2C-2 _____ cfm | | | | 1 |
| 2 | Measure entering air temp & humidity _____ F, _____ % RH | | | | 2 |
| 3 | Estimate leaving air humidity; leaving air should not damage building and equipment; otherwise postpone test | | | | 3 |
| 4 | Measure & adjust steam temp & pressure to within 1 psi of specified (*_____ psi) _____ psi _____ F<br>Is steam saturated? | | | | 4 |
| 5 | Set humidifier control to discharge steam at full load | | | | 5 |
| 6 | Run system for at least 10 minutes | | | | 6 |
| 7 | Take 3 sets of test data at 5 min intervals: | | | | 7 |

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| Ent air temp | _____ | _____ | _____ | F |
| Lvg air temp | _____ | _____ | _____ | F |
| Ent air humidity | _____ | _____ | _____ | % RH |
| Lvg air humidity | _____ | _____ | _____ | % RH |

COMMENTS:___________________________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HUMIDIFIER
continued
Page 19

AH no.________________
Humidifier no. ________

Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | Calculate humidifier capacity: | | | | 8 |
| 8a | Saturated water vapor of air, Psw: | | | | 8a |

$$P_{sw} = e^{(15.4638 - [7284/(Td-392)]}$$

$$(P_{sw})_{ent} = e^{(15.4638 - [7284/\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

$$(P_{sw})_{lvg} = e^{(15.4638 - [7284/\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

8b Vapor pressure, Pw: 8b

$$P_w = RH \times P_{sw}$$

$$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

$$(P_w)_{lvg} = 0.5 \times (P_{sw})_{lvg} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

8c Humidity ratio, W: 8c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$$(W)_{ent} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} = \_\_\_\_\_ \text{ lb vapor/lb dry air}$$

COMMENTS:______________________________________________
______________________________________________
______________________________________________

TEST WORK SHEET WS 5B-2 -- AIR HANDLING SYSTEM (COMPONENT TEST), HUMIDIFIER continued



AH no.________________ Date__________

Humidifier no. ________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

$$(W)_{lvg} = 0.622 \times \frac{\_\_\_\_}{\_\_\_\_ - \_\_\_\_} = \_\_\_\_ \text{ lb vapor/lb dry air}$$

8d Specific volume of air, v: 8d

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b} (1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_ + 460)}{P_b} (1 + 1.6078 \times W) = \_\_\_\_ \text{ cu ft/lb}$$

8e Mass flow rate of air, M: 8e

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_} = \_\_\_\_ \text{ lb/min}$$

8f Humidifier capacity, C: 8f

$$C = 60\ M \times [(W)_{lvg} - (W)_{ent}]$$

$$= 60 \times \_\_\_\_ \times (\_\_\_\_ - \_\_\_\_) = \_\_\_\_ \text{ Btu/n}$$

9 Repeat calculations for all 3 sets of data,
Averaged humidifier capacity: 9

$$(\_\_\_\_ + \_\_\_\_ + \_\_\_\_)/3 = \_\_\_\_ \text{ Btu/h}$$

10 Acceptance criteria 10

C > 0.95 x * capacity > 0.95 x ____ > ____

Humidifier does not "spit"

COMMENTS:________________________________________

## 6.1 INSPECTION CHECK LIST CL 6A-1 -- EMCS

Page 1

Supplier____________________ Date__________
System model________________ Inspection agent_________________
CPU make,model______________ Commissioning team_______________
CPU serial no.______________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| General: | | | | | | |
| 1 | Control diagrams, O & M manuals complete | | | | | 1 |
| 2 | Specified test equipment complete: | | | | | |
| 2a | PROM programmer | | | | | 2a |
| 2b | FID/MUX tester | | | | | 2b |
| 2c | Data environment simulator | | | | | 2c |
| 2d | Others | | | | | 2d |
| 3 | General appearances, no apparent damage | | | | | 3 |
| 4 | Any interfacing with existing system? If so: | | | | | 4 |
| 4a | Has existing system been tested? List items tested: ________ ________ ________ | | | | | 4a |
| 5 | Are all required master control room (MCR) equipment installed? Verify component models with submittals: Model / Serial no. | | | | | 5 |
| 5a | CCU ________ | | | | | 5a |
| 5b | Disk drive ________ | | | | | 5b |
| 5c | Oper. console ________ | | | | | 5c |
| 5d | Graphic device ________ | | | | | 5d |
| 5e | Logging printer ________ | | | | | 5e |
| 5f | Alarm printer ________ | | | | | 5f |
| 5g | Others ________ | | | | | 5g |
| 6 | Verify field equipment models with submittals: Make & Model / Software version | | | | | 6 |
| 6a | FID ________ | | | | | 6a |
| 6b | Mux ________ | | | | | 6b |
| 6c | Temperature sensor________ | | | | | 6c |
| 6d | Humidity sensor | | | | | 6d |
| 6e | Pressure sensor | | | | | 6e |
| 6f | Flow sensor | | | | | 6f |

INSPECTION CHECK LIST CL 6A-1 -- EMCS continued



Date___________

| NO. | DESCRIPTION | YES | NO | N/A | REMARKS | NO. |
|---|---|---|---|---|---|---|
| 6g | Temperature transmitter | | | | | 6g |
| 6h | Humidity transmitter | | | | | 6h |
| 6i | Pressure transmitter | | | | | 6i |
| 6j | Flow transmitter | | | | | 6j |
| 6k | Others_________________ _________________ | | | | | 6k |
| 7 | Equipment access space adequate | | | | | 7 |
| 8 | Electrical connections tight, labeled | | | | | 8 |
| 9 | Equipmant and wiring grounding (control room equipment, raised floor, wire troughs and field equipment) | | | | | 9 |
| 10 | High and low voltage line separation | | | | | 10 |
| 11 | Integraty of electrical insulation | | | | | 11 |
| 12 | Identification of wires and terminals | | | | | 12 |
| 13 | FID & MUX cabinets as required | | | | | 13 |
| 14 | FID & MUX cabinet locks as required Spare keys supplied as required | | | | | 14 |
| 15 | Indicating lights of FID & MUX as required | | | | | 15 |
| 16 | Temperature sensors installed properly | | | | | 16 |
| 17 | Averaging temperature sensors required? | | | | | 17 |
| 18 | No apparant conduction loss of temperature sensor supporting rod | | | | | 18 |
| 19 | No apparant radiation effect for temperature sensor | | | | | 19 |
| 20 | Adequate protection from moisture for temperature sensors on ch. water pipes | | | | | 20 |
| 21 | Humidity sensor installed properly | | | | | 21 |
| 22 | Water protection for humidity sensor | | | | | 22 |
| 23 | Pressure sensors installed properly | | | | | 23 |
| 24 | Flow sensing devices installed properly | | | | | 24 |
| 25 | Pressure & flow sensing devices have flow straightners or adequate pipe | | | | | 25 |
| 26 | Adequate protection of transmitters for high temperature | | | | | 26 |
| 27 | Equipment surface paint complete | | | | | 27 |
| 28 | Operation of dampers and valves, no hunting noticed | | | | | 28 |

COMMENTS:______________________________________________________________
______________________________________________________________________
______________________________________________________________________

## 6.2 TEST WORK SHEET WS 6B-1 -- EMCS GENERAL

Page 1

Supplier____________________ Date__________
EMCS system model____________ Inspection agent________________
CPU make,model______________ Commissioning team_______________
CPU serial no.______________ _______________
Software version____________ _______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | System general test: | | | | |
| 1 | Shut all EMCS equipment off | | | | 1 |
| 2 | Energize all EMCS equipment: | | | | 2 |
| 2a | Equipment in central control rm.: | | | | 2a |
| | central control unit | | | | |
| | storage unit | | | | |
| | operator's unit | | | | |
| | monitor | | | | |
| | logging printer(s) | | | | |
| | alarm printer(s) | | | | |
| | display unit(s) | | | | |
| | others | | | | |
| 2b | Field equipment | | | | 2b |
| | FIDs | | | | |
| | MUXs | | | | |
| | others | | | | |
| 3 | Initiate system startup (see system supplier's instructions) | | | | 3 |
| 4 | Enter command to display content of stored files: | | | | 4 |
| | program to load and initiate computer | | | | |
| | operating program for peripheral devices | | | | |
| | operating program for file management | | | | |
| | text editor program | | | | |
| | language processor | | | | |
| | linking program | | | | |
| | assembler | | | | |
| | others | | | | |

COMMENTS:____________________________________________________________
___________________________________________________________________

TEST WORK SHEET WS 6B-1 -- EMCS GENERAL continued

Page 2

Supplier__________________ Date__________

EMCS system model_________

Software version_________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 5 | Enter following commands from operator's console to test system responses. When system responds, check for correctness. | | | | 5 |
| 5a | Log on with incorrect ID | | | | 5a |
| 5b | Log on with correct ID | | | | 5b |
| 5c | Enter at least 5 correct commands<br>__________________<br>__________________<br>__________________<br>__________________<br>__________________ | | | | 5c |
| 5d | Enter at least 5 incorrect and incomplete commands and check error messages<br>__________________<br>__________________<br>__________________<br>__________________<br>__________________ | | | | 5d |
| 5e | Command to start certain HVAC equipment | | | | 5e |
| 5f | Command to stop certain HVAC equipment | | | | 5f |
| 5g | Command to disable certain FIDs | | | | 5g |
| 5h | Command to enable the FIDs disabled in 5g | | | | 5h |
| 5i | Command to disable certain MUXs | | | | 5i |
| 5j | Command to enable the MUXs disabled in 5i | | | | 5j |
| 5k | Command to disable certain sensor inputs | | | | 5k |
| 5l | Command to address the disabled sensors in 5k | | | | 5l |
| 5m | Command to enable the points in 5k | | | | 5m |
| 5n | Enter commands of higher access level than allowed | | | | 5n |
| 5o | Enter commands for help function | | | | 5o |
| 5p | Enter invalid commands | | | | 5p |
| 5q | Cancel commands entered previously | | | | 5q |
| 5r | Command to display certain digital points | | | | 5r |
| 5s | Command to display certain analog points | | | | 5s |
| 5t | Command to change set point within limits of certain controllers | | | | 5t |

TEST WORK SHEET WS 6B-1 -- EMCS GENERAL continued

Page 3

Supplier___________________ Date__________
EMCS system model_________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 5u | Command to change set point outside limits of certain controllers | | | | 5u |
| 5v | Command to change high limits of certain control points | | | | 5v |
| 5w | Command to change low limits of certain control points | | | | 5w |
| 5x | Command to change certain scale factor | | | | 5x |
| 5y | Command control of certain equipment from EMCS to manual control | | | | 5y |
| 5z | Command same equipment in 5y from manual to automatic mode | | | | 5z |
| 5aa | Command to change time of certain HVAC control actions | | | | 5aa |
| 5bb | Command to generate report and examine report content and format:<br>All point report of all systems:<br>____________ (enter system no.)<br>____________<br>____________<br>____________<br>Trend of certain points:<br>____________(enter point no.)<br>____________<br>____________<br>____________<br>Timed display of certain reports:<br>____________<br>____________<br>____________ | | | | 5bb |
| 5cc | Initiate alarm conditions of certain points to generate alarm reports:<br>____________(enter point no.)<br>____________<br>____________<br>____________ | | | | 5cc |
| 5dd | Enter other commands | | | | 5dd |
| 5ee | Log off system | | | | 5ee |

COMMENTS:______________________________________________
_______________________________________________________
_______________________________________________________

## 6.3 TEST WORK SHEET WS 6B-2 -- EMCS OVERALL PERFORMANCE TEST, TEMPERATURE, HUMIDITY, AND PRESSURE

Page 1

Supplier____________________ Date__________
EMCS system model___________ Inspection agent_______________
Software version____________ Commissioning team_______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | **Temperature, humidity, and pressure points:** | | | | |
| | Enter point no.__________ | | | | |
| | sensor kind________ | | | | |
| | service____________ | | | | |
| | test sensor in: pipe________ space___ | | | | |
| | (check one) duct________ | | | | |
| | simulated __ | | | | |
| 1 | Prepare two way communication between EMCS sensor location and central control room | | | | 1 |
| 2 | Place sensor in place | | | | 2 |
| | **First point (low range):** | | | | |
| 3 | If simulated environment is used, adjust medium to around low range of sensor | | | | 3 |
| 4 | Wait sufficient time for sensor to stablize | | | | 4 |
| 5 | Coordinate time between site and central control room for taking readings | | | | 5 |
| 6 | Take readings simultaneously<br>Reading of sensor at site________<br>Reading at central control_______ | | | | 6 |

COMMENTS:________________________________________________________

TEST WORK SHEET WS 6B-2 -- EMCS OVERALL PERFORMANCE TEST, TEMPERATURE, HUMIDITY, AND PRESSURE continued
Page 2

Supplier__________________ Date__________
EMCS system model_________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7 | Difference of two readings = _____ - _____<br>= _____<br>* _____ | | | | 7 |

Second point (high range):

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | If simulated environment is used, adjust medium to around 3/4 of high range of sensor<br>Set medium = 0.75 x *_____ = _____ | | | | 8 |
| 9 | Wait sufficient time for sensor to stablize | | | | 9 |
| 10 | Coordinate time between site and central control room for taking readings | | | | 10 |
| 11 | Take readings simultaneously<br>Reading of sensor at site________<br>Reading at central control_______ | | | | 11 |
| 12 | Difference of two readings = _____ - _____<br>= _____ gpm<br>* _____ | | | | 12 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

## 6.4 TEST WORK SHEET WS 6B-3 -- EMCS OVERALL PERFORMANCE TEST, FLOW

Page 1

Supplier____________________ Date__________
EMCS system model___________ Inspection agent________________
HVAC system_________________ Commissioning team______________
Software version____________ _______________
_______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Flow points:<br>Enter point no.__________<br>sensor kind________<br>service____________ | | | | |
| 1 | Prepare two way communication between EMCS sensor location and central control room | | | | 1 |
| 2 | Remove primary flow sensor from EMCS | | | | 2 |
| 3 | Connect flow simulating instrument to EMCS | | | | 3 |
| | First point (zero flow): | | | | |
| 4 | Set simulating instrument to zero signal | | | | 4 |
| 5 | Take a reading from central control<br>_______ gpm | | | | 5 |
| 6 | Difference of reading from zero _______ | | | | 6 |
| | Second point (high flow range): | | | | |
| 7 | Adjust simulating instrument to around 3/4 of equivalent high flow<br>Flow = 0.75 x *_____ gpm = _____ gpm<br>Equivalent flow signal:<br>For manometer _____ in. w.c.<br>For count type_____ counts/min<br>For other type_____ ( ) | | | | 7 |
| 8 | Take a reading from central control<br>______ gpm | | | | 8 |

COMMENTS:_______________________________________________
_______________________________________________
_______________________________________________

TEST WORK SHEET WS 6B-3 -- EMCS OVERALL PERFORMANCE TEST, FLOW continued
Page 2

Supplier__________________ Date__________
EMCS system model__________
HVAC system______________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9 | Calculate flow rate from data in 7<br>For manometer type flow (SE-37 or 39): | | | | 9 |

$$\text{Flow rate} = 44.75\ (K\ Y\ d^2\ F_a)\ \left(\frac{h_w}{D}\right)^{(1/2)}$$

$$= 44.75\ (\_\_\_ \times \_\_\_ \times \_\_\_^2 \times \_\_\_)\ \left(\frac{\_\_}{\_\_}\right)^{(1/2)}$$

= _____ gpm

For turbine and vortex shedding type (SE-41):

$$\text{Flow rate} = 60\ (f\ /\ k)$$

$$= 60 \times \left(\frac{\_\_}{\_\_}\right)$$

= _____ gpm

For other types (provide calculations below)

| | | | | | |
|---|---|---|---|---|---|
| 10 | Difference of calculated (in 9) and central control indicated (in 8)<br>= _____ - _____ = _____ gpm<br>* _____ | | | | 10 |

COMMENTS:____________________________________________
____________________________________________
____________________________________________

## 6.5 TEST WORK SHEET WS 6B-4 -- EMCS OVERALL PERFORMANCE TEST, FOR ENERGY CALCULATIONS

Page 1

Supplier__________ Date__________
EMCS system model__________ Inspection agent__________
HVAC systm__________ Commissioning team__________
Software version__________ __________
__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Instantaneous energy rate for water: | | | | |
| | System __________ | | | | |
| 1 | Command to print a set of all point data for a system | | | | 1 |
| 2 | Indicated water entering heat exchanger temp____ F | | | | 2 |
| 3 | Indicated water leaving heat exchanger temp____ F | | | | 3 |
| 4 | Calculate temperature difference = _____ - _____ = _____ F | | | | 4 |
| 5 | Indicated water flow rate _____ gpm | | | | 5 |
| 6 | Calculate energy rate = 500 x (temp difference) x (flow rate) = 500 x _____ x _____ = _____ Btu/h | | | | 6 |
| 7 | Indicated energy rate _____ | | | | 7 |
| 8 | Compare calculated and indicated energy rates | | | | 8 |

COMMENTS:______________________________
______________________________
______________________________

TEST WORK SHEET WS 6B-4 -- EMCS OVERALL PERFORMANCE TEST, FOR ENERGY CALCULATIONS
continued

Page 2

Supplier__________________ Date__________
EMCS system model__________
HVAC system_______________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

Instantaneous energy rate for steam:

System _______________

1 Command to print a set of all point data for a system 1
2 Indicated steam temperature _____ F 2
3 Indicated steam pressure _____ F 3
4 Indicated condensate temp _____ F 4
5 Indicated steam flow rate _____ lb/h 5
6 Enthalpy of steam (from 2,3 & steam table) = _____ Btu/lb 6
7 Enthalpy of water (from 4 & steam table) = _____ Btu/lb 7

8 Energy rate = (enthalpy of steam - enthalpy of water) x steam flow rate 8
= (_____ - _____) x _____
= _____ Btu/h

9 Indicated energy rate _____ 9

10 Compare calculated and indicated energy rates 10

COMMENTS:______________________________________________
_______________________________________________________
_______________________________________________________

TEST WORK SHEET WS 6B-4 -- EMCS OVERALL PERFORMANCE TEST, FOR ENERGY CALCULATIONS
continued

Page 3

Supplier________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Accumulated energy (to be tested for all steam and water consumption): | | | | |
| | System _______________ | | | | |
| 1 | Command to print energy consumption rate (Btu/h) of system to be tested at 1 minute intervals for 10 minutes in unit of Btu/h | | | | 1 |
| 2 | Command to accumulate energy amount for the same system and same time as in 1, Btu | | | | 2 |
| 3 | Average the ten instantaneous energy rates _____ Btu/h | | | | 3 |
| 4 | Calculate the total energy of the 10 minutes = 10/60 x ______(from 3) = ______ Btu | | | | 4 |
| 5 | Indicated energy of the same period (from 2) = _____ Btu | | | | 5 |
| 6 | Difference of calculated and indicated energy = _____(from 5) - _____(from 4) = _____ Btu | | | | 6 |
| 7 | Percentage difference = [1 - ( _____(from 6) / _____(from 4) ] x 100 = _____ % | | | | 7 |

COMMENTS:______________________________________________
______________________________________________
______________________________________________

TEST WORK SHEET WS 6B-4 -- EMCS OVERALL PERFORMANCE TEST, FOR ENERGY CALCULATIONS
continued

Page 4

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Accumulated energy (to be tested for all electric consumption): | | | | |
| | System _______________ | | | | |
| 1 | Command to print elec. energy consumption rate (W) of system to be tested at 1 minute intervals for 10 minutes | | | | 1 |
| 2 | Command to accumulate elec. energy amount for the same system and same time as in 1, Wh | | | | 2 |
| 3 | Average the ten instantaneous energy rates _____ W | | | | 3 |
| 4 | Calculate the total elec. energy of the 10 minutes = 10/60 x ______(from 3) = ______ Wh | | | | 4 |
| 5 | Indicated energy of the same period (from 2) = _____ Wh | | | | 5 |
| 6 | Difference of calculated and indicated energy = _____(from 5) - _____(from 4) = _____ Wh | | | | 6 |
| 7 | Percentage difference = [1 - ( _____(from 6) / _____(from 4) ] x 100 = _____ % | | | | 7 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

## 6.6 TEST WORK SHEET WS 6B-5 -- EMCS APPLICATION SOFTWARE TEST, SCHEDULED START/STOP

Supplier____________________ Date__________
EMCS system model___________ Inspection agent________________
HVAC system_________________ Commissioning team______________
Software version____________ ______________
______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Start time set ________<br>Stop time set _________<br>Days set: weekday _____<br>weekend _____<br>holiday _____<br>Season: heating ____<br>cooling ____<br>Time delay required? Delay time _____ | | | | 1 |
| 2 | Record current equipmant operation mode<br>on _____<br>off _____ | | | | 2 |
| 3 | Enter command to put equipment under program | | | | 3 |
| 4 | Observe equipment operation when set time is reached and record equipment operation mode<br>on _____<br>off _____<br>time delay time _____ | | | | 4 |
| 5 | Manually start or stop equipment | | | | 5 |
| 6 | EMCS issues alarm | | | | 6 |
| 7 | Test conclusion | | | | 7 |

COMMENTS:________________________________________________
__________________________________________________________
__________________________________________________________

## 6.7 TEST WORK SHEET WS 6B-6 -- EMCS APPLICATION SOFTWARE TEST, OPTIMUM START/STOP

Page 1

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.
3. Observation of equipment operation for this test should be at equipment start/stop time which varies according to outdoor conditions.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Days set: weekday _____<br>weekend _____<br>holiday _____<br>Season: heating ____<br>cooling ____<br>Time delay required? Delay time _____ | | | | 1 |
| 2 | Record current equipmant operation mode<br>on _____<br>off _____ | | | | 2 |
| 3 | Enter command to put equipment under program | | | | 3 |

COMMENTS:______________________________________________________________

________________________________________________________________________

________________________________________________________________________

TEST WORK SHEET WS 6B-6 -- EMCS APPLICATION SOFTWARE TEST, OPTIMUM START/STOP continued

Page 2

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

| Steps | Check mark | Fail & Pass | Remarks | No. |
|---|---|---|---|---|
| Optimum Start - : | | | | |
| 4 Display representative space temperature (or return air temperature) at close intervals (e.g. 1 minute) | | | | 4 |
| 5 Observe equipment operation mode change from off to on<br>When equipment is switched to occupied mode record indoor air temperature, _____ F.<br>This temperature shall not differ more than 3 F from specified room temperature (or tolerance specified) | | | | 5 |
| Optimum stop - : | | | | |
| 6 Observe equipment operation mode change from on to off<br>When equipment is stopped, keep displaying indoor air temperature until end of specified occupancy time, space temp shall not differ more than 3 F from specified room temp during occupied period (or as specified) | | | | 6 |
| 7 Manually start or stop equipment | | | | 7 |
| 8 EMCS issues alarm | | | | 8 |
| 9 Test conclusion | | | | 9 |

COMMENTS:_______________________________________________

## 6.8 TEST WORK SHEET WS 6B-7 -- EMCS APPLICATION SOFTWARE TEST, DUTY CYCLING

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Specified maximum space temp ______<br>Specified minimum space temp ______<br>Specified minimun cycling time _____min | | | | 1 |
| 2 | Enter command to put equipment under duty cycling schedule program | | | | 2 |
| 3 | Display space temperature (at 5 minute intervals) and equipment operation status | | | | 3 |
| 4 | Verify that the equipment is cycling and the space temp does not go beyond the max. or min. specified temp | | | | 4 |
| 5 | Enter command or reset temp controller to raise or lower space set temp | | | | 5 |
| 6 | Verify that the equipment is cycling and the space temp does not go beyond the max-min specified temp band | | | | 6 |
| 7 | Verify that the specified minimum on time is not violated during the entire test period | | | | 7 |
| 8 | Restore setting of temp controller | | | | 8 |
| 9 | Test conclusion | | | | 9 |

COMMENTS:______________________________________________________________

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## 6.9 TEST WORK SHEET WS 6B-8 -- EMCS APPLICATION SOFTWARE TEST, ELECTRICAL DEMAND LIMITING

Page 1

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Time applicable: start _______<br>end _________<br>Days applicable: weekday _____<br>weekend _____<br>holiday _____<br>Meter reset interval _________ min<br>Average power ________________ kw<br>Equipment under control: | | | | 1 |

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Equipment name | | | | |
| Priority level | | | | |
| Delay time (min) | | | | |
| Min off (min) | | | | |
| Min on (min) | | | | |
| Max off (min) | | | | |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 6B-8 -- EMCS APPLICATION SOFTWARE TEST, ELECTRICAL DEMAND LIMITING continued
Page 2

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | 5 6 7 8 | | | | |
| | Equipment name | | | | |
| | Priority level | | | | |
| | Delay time (min) | | | | |
| | Min off (min) | | | | |
| | Min on (min) | | | | |
| | Max off (min) | | | | |
| 2 | Enter command to put program in operation | | | | 2 |
| 3 | Turn on HVAC equipment and/or increase electric load | | | | 3 |
| 4 | Verify equipment shut-down and record equipment on/off time | | | | 4 |
| | 1 2 3 4 | | | | |
| | Equipment | | | | |
| | Time shed | | | | |
| | Time restored | | | | |
| | Off time (min) | | | | |
| | On time (min) | | | | |
| | 5 6 7 8 | | | | |
| | Equipment | | | | |
| | Time shed | | | | |
| | Time restored | | | | |
| | Off time (min) | | | | |
| | On time (min) | | | | |
| 5 | Confirm that equipment shedding sequence agrees with priority list | | | | 5 |
| 6 | Confirm that equipment on/off times do not exceed specified max and min limits | | | | 6 |
| 7 | Confirm equipment rotation within the same priority level, if specified | | | | 7 |
| 8 | Test conclusion | | | | 8 |

COMMENTS:____________________________________________________________
_____________________________________________________________________

## 6.10 TEST WORK SHEET WS 6B-9 -- EMCS APPLICATION SOFTWARE TEST, DAY-NIGHT SETBACK

Page 1

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Days applicable: weekday _____<br>weekend _____<br>holiday _____<br>Season: heating ____, cooling ____<br>Setback time: start _____, end _____<br>Occupied time set temp ______ F<br>Unoccupied time set temp _____ F | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3 | Enter setback time to 5 minutes beyond current time | | | | 3 |
| 4 | Confirm system operation changes when time reaches setback time | | | | 4 |
| | For heating test: | | | | |
| 5 | Reset setback temp 3 F higher than present space temp | | | | 5 |
| 6 | Confirm system cycling to satisfy temp setting | | | | 6 |
| 7 | Confirm air damper positions in accordance to spec | | | | 7 |
| 8 | Change setback time so that current control is under occupied time | | | | 8 |
| 9 | Confirm system is under occupied mode (e.g. fan and damper) | | | | 9 |

COMMENTS:____________________________________________________________
______________________________________________________________________
______________________________________________________________________

TEST WORK SHEET WS 6B-9 -- EMCS APPLICATION SOFTWARE TEST, DAY-NIGHT SETBACK continued

Page 2

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | For cooling test: | | | | |
| 10 | Reset setback temp 3 F lower than present space temp | | | | 10 |
| 11 | Confirm system cycling to satisfy temp setting | | | | 11 |
| 12 | Confirm air damper positions in accordance with spec | | | | 12 |
| 13 | Change setback time so that current control is under occupied time | | | | 13 |
| 14 | Confirm system is under occupied mode (e.g. fan and damper) | | | | 14 |
| 15 | Restore setback time and temp to specified values | | | | 15 |
| 16 | Test conclusion | | | | 16 |

COMMENTS:___________________________________________

## 6.11 TEST WORK SHEET WS 6B-10 -- EMCS APPLICATION SOFTWARE TEST, DRY BULB ECONOMY CYCLE

Supplier________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Change-over temp ________ F | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3 | Obtain a current report of system:<br>Outdoor air temp _____ F<br>Return air temp _____ F<br>Outdoor sir damper position _____<br>Return air damper position _____<br>Mixed air temp _____ F | | | | 3 |
| 4 | Compare outdoor air and change-over temp., if:<br>$T_{oa} > T_{co}$, go to steps 5 to 9<br>$T_{oa} < T_{co}$, go to steps 8 to 12 | | | | 4 |
| 5 | Verify that outdoor damper is at min OA position and return damper position is appropriate | | | | 5 |
| 6 | Verify that coil valve positions are apporpriate | | | | 6 |
| 7 | Raise change-over temp 3 F above outdoor temp | | | | 7 |
| 8 | Verify that outdoor and return dampers are under local control (modulating) | | | | 8 |
| 9 | Verify that coil valve positions are apporpriate | | | | 9 |
| 10 | Lower change-over temp 3 F below outdoor temp | | | | 10 |
| 11 | Verify that outdoor damper is at min OA position and return damper position is appropriate | | | | 11 |
| 12 | Verify that coil valve positions are apporpriate | | | | 12 |
| 13 | Test conclusion | | | | 13 |
| 14 | Restore change-over temp setting | | | | 14 |

## 6.12 TEST WORK SHEET WS 6B-11 -- EMCS APPLICATION SOFTWARE TEST, ENTHALPY ECONOMY CYCLE

Page 1

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Program requirement varies, see project specification and change test work sheet accordingly.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Confirm that program requires temp and humidity of both outdoor and return air | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3 | Obtain a current report of system:<br>Outdoor air temp _____ F<br>Outdoor air humidity _____ % RH or<br>_____ F w.b. and<br>_____ F d.p.<br>Outdoor air enthalpy _____ Btu/lb<br>Return air temp _____ F<br>Return air humidity _____ % RH or<br>_____ F w.b. and<br>_____ F d.p.<br>Return air enthalpy _____ Btu/lb | | | | 3 |
| 4 | Compare outdoor and return air enthalpies. If:<br>$H_{oa} > H_{ra}$, go to 5<br>$H_{oa} < H_{ra}$, go to 6 | | | | 4 |
| 5 | Verify that the OA damper is at min position and RA damper position is proper | | | | 5 |

COMMENTS:______________________________________________
_______________________________________________________
_______________________________________________________

TEST WORK SHEET WS 6B-11 -- EMCS APPLICATION SOFTWARE TEST, ENTHALPY ECONOMY CYCLE continued

Page 2

Supplier__________________ Date__________

EMCS system model__________

HVAC system_______________

Software version__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6 | Substitute outdoor temp and humidity sensors with simulators | | | | 6 |
| 7 | Divide a psychromatic chart into regions as outlined in paragraph 7.5.3.3 of EXHIBIT 5-B | | | | 7 |
| 8 | Manipulate temp and humidity sensors so that OA conditions are within each of the regions where $H_{oa} < H_{ra}$ | | | | 8 |
| 9 | Verify that OA and RA damper positions are in accordance with specifications<br><br>Region OA RA<br>1<br>2<br>3 | | | | 9 |
| 10 | Restore temp and humidity sensors | | | | 10 |
| 11 | Test conclusion | | | | 11 |

COMMENTS:______________________________________________

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_______________________________________________________

## 6.13 TEST WORK SHEET WS 6B-12 -- EMCS APPLICATION SOFTWARE TEST, VENTILATION AIR CONTROL

Page 1

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Perform this test during occupied period.
3. This form is designed for specs requiring outdoor damper positions be based on comparison of outdoor and space temp. Modify form if the requirement is different.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Days applicable: weekday _____<br>weekend _____<br>holiday _____<br>Season: heating ____, cooling ____<br>Space temp: _____ F<br>Occupied time: start ______<br>end ________<br>AH unit: start time _______<br>stop time ________ | | | | 1 |
| 2 | Time of test ______ | | | | 2 |
| 3 | Enter command to put program in operation | | | | 3 |
| 4 | Verify that OA damper is open | | | | 4 |
| | For heating mode test: | | | | |
| 5 | Change occupied/unoccupied schedule so that current time is about 15 minutes before occupied period, then go to step 6 or 9 | | | | 5 |
| 6 | If outdoor temp is higher than space temp, verify that dampers are under local loop control | | | | 6 |

COMMENTS:____________________________________________________________
______________________________________________________________________
______________________________________________________________________

TEST WORK SHEET WS 6B-12 -- EMCS APPLICATION SOFTWARE TEST, VENTILATION AIR CONTROL continued

Page 2

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7 | Raise space temp setting 3 F above outdoor temp | | | | 7 |
| 8 | Verify that OA damper is closed | | | | 8 |
| 9 | Lower space temp setting 3 F below outdoor temp | | | | 9 |
| 10 | Verify that dampers are under local loop control | | | | 10 |
| | For cooling mode test: | | | | |
| 11 | Change occupied/unoccupied schedule so that current time is about 15 minutes before occupied period, then go to step 12 or 15 | | | | 11 |
| 12 | If outdoor temp is higher than space temp, verify that outdoor damper is closed to minimum position | | | | 12 |
| 13 | Raise space temp setting 3 F above outdoor temp | | | | 13 |
| 14 | Verify that dampers are under local loop control (modulating) | | | | 14 |
| 15 | If outdoor temp is lower than space temp, verify that dampers are under local loop control | | | | 15 |
| 16 | Lower space temp setting 3 F below outdoor temp | | | | 16 |
| 17 | Verify that outdoor damper is closed | | | | 17 |
| 18 | Restore occupied/unoccupied schedule and temp settings | | | | 18 |
| 19 | Test conclusion | | | | 19 |

COMMENTS:____________________________________________________________

## 6.14 TEST WORK SHEET WS 6B-13 -- EMCS APPLICATION SOFTWARE TEST, HEATING/COOLING COIL TEMPERATURE RESET

Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Perform this test during occupied period.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Coil type: heating _____, cooling _____ | | | | 1 |
| 2 | System input:<br>Reset upper temp limit _____ F<br>Reset lower temp limit _____ F<br>Index temp: outdoor temp _____<br>zone temp _____<br>Space humidity limit:<br>____ % RH, ____ F w.b., ____ F d.p. | | | | 2 |
| 3 | Enter command to put program in operation | | | | 3 |
| 4a | Substitute index temp sensor with temp simulator, or | | | | 4a |
| 4b | Place index temp sensor in temp bath | | | | 4b |
| 5 | Increase simulated temp or bath temp | | | | 5 |
| 6 | Observe coil discharge temp, it should move lower | | | | 6 |
| 7 | Verify that discharge temp does not go below specified low limit | | | | 7 |
| 8 | Decrease simulated temp of bath temp | | | | 8 |
| 9 | Observe coil discharge temp, it should move higher | | | | 9 |
| 10 | Verify that discharge temp does not go above specified high limit | | | | 10 |
| 11 | For cooling coils which specify high space humidity limits, change the humidity limit to a lower level | | | | 11 |
| 12 | Verify that the cooling coil discharge temp decreases | | | | 12 |
| 13 | Restore temp sensors | | | | 13 |
| 14 | Test conclusion | | | | 14 |

COMMENTS:______________________________________________

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## 6.15 TEST WORK SHEET WS 6B-14 -- EMCS APPLICATION SOFTWARE TEST, HOT WATER TEMPERATURE RESET

Supplier__________________ Date__________
EMCS system model_________
HVAC system_______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Perform this test during occupied period.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Reset schedule:<br>Outdoor temp / HW temp<br>High _____ F _____ F<br>Low _____ F _____ F | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3a | Substitute outdoor temp sensor with temp simulator, or | | | | 3a |
| 3b | Place outdoor temp sensor in temp bath | | | | 3b |
| 4 | Increase simulated temp or bath temp to below the high limit | | | | 4 |
| 5 | Observe hot water temp, it should move lower | | | | 5 |
| 6 | Increase simulated temp or bath temp to 5 F beyond high limit | | | | 6 |
| 7 | Verify that hot water temp does not go below specified limit | | | | 7 |
| 8 | Decrease simulated temp or bath temp to above low limit | | | | 8 |
| 9 | Observe hot water temp, it should move higher | | | | 9 |
| 10 | Decrease simulated temp or bath temp to 5 F beyond low limit | | | | 10 |
| 11 | Verify that hot water temp does not go above specified limit | | | | 11 |
| 12 | Restore temp sensors | | | | 12 |
| 13 | Test conclusion | | | | 13 |

COMMENTS:______________________________________________
_______________________________________________________
_______________________________________________________

## 6.16 TEST WORK SHEET WS 6B-15 -- EMCS APPLICATION SOFTWARE TEST, CHILLED WATER TEMPERATURE RESET

Page 1

Supplier_______________ Date__________
EMCS system model_________
HVAC system______________
Software version__________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.
2. Perform this test during occupied period.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Reset schedule:<br>Space temp / Valve position / CHW temp<br>High _____ F _____ % _____ F<br>Low _____ F _____ % _____ F<br>Space high humidity limit:<br>_____ % RH<br>_____ F wb<br>_____ F dp | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3a | Substitute space temp sensor with temp simulator, or | | | | 3a |
| 3b | Place space temp sensor in temp bath, or | | | | 3b |
| 3c | Be ready to change valve position sensor (or control signal feedback sensor) | | | | 3c |
| 4a | Change temp simulator to raise temp (not over the limit), or | | | | 4a |
| 4b | Raise bath temp (not over the limit), or | | | | 4b |
| 4c | Move valve position or feedback sensor to indicate opening (not over the limit) | | | | 4c |
| 5 | Verify that chilled water temp is decreasing | | | | 5 |
| 6a | Change temp simulator to raise temp 3 F beyond limit, or | | | | 6a |
| 6b | Raise bath temp 3 F beyond limit, or | | | | 6b |

COMMENTS:____________________________________________

TEST WORK SHEET WS 6B-15 -- EMCS APPLICATION SOFTWARE TEST, CHILLED WATER TEMPERATURE RESET continued



Supplier__________________ Date__________

EMCS system model_________

HVAC system_______________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6c | Move valve position or feedback sensor to indicate valve fully open | | | | 6c |
| 7 | Verify that chilled water temp does not drop below low limit | | | | 7 |
| 8a | Change temp simulator to lower temp (not below the limit), or | | | | 8a |
| 8b | Lower bath temp (not below the limit), or | | | | 8b |
| 8c | Move valve position or feedback sensor to indicate valve is closing (not over the limit) | | | | 8c |
| 9 | Verify that chilled water temp is increasing | | | | 9 |
| 10a | Change temp simulator to lower temp 3 F beyond limit, or | | | | 10a |
| 10b | Lower bath temp 3 F beyond limit, or | | | | 10b |
| 10c | Move valve position or feedback sensor toindicate fully closed valve | | | | 10c |
| 11 | Verify that chilled water temp does not increase above high limit | | | | 11 |
| 12 | Substitute space humidity sensor with humidity simulator | | | | 12 |
| 13 | Change humidity simulator to raise space humidity beyond high limit | | | | 13 |
| 14 | Verify that chilled water temp decreases | | | | 14 |
| 15 | If more than one zone reset chilled water temp, repeat procedures for all zones | | | | 15 |
| 16 | Restore temp, humidity, or position (or feedback) sensors | | | | 16 |
| 17 | Test conclusion | | | | 17 |

COMMENTS:______________________________________________

## 6.17 TEST WORK SHEET WS 6B-16 -- EMCS APPLICATION SOFTWARE TEST, CONDENSER WATER TEMPERATURE RESET

Page 1

Supplier____________________  Date___________
EMCS system model__________
HVAC system_______________
Software version___________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" columns. Enter remarks if necessary.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | System input:<br>Reset schedule:<br>OA wet bulb temp / OA dry bulb temp / Cond water temp<br>High _____ F _____ F _____ F<br>Low _____ F _____ F _____ F<br>Condenser water low limit _____ F | | | | 1 |
| 2 | Enter command to put program in operation | | | | 2 |
| 3 | Substitute outdoor temp sensor with temp simulator | | | | 3 |
| 4 | Substitute outdoor humidity sensor with humidity simulator | | | | 4 |
| 5 | Manipulate temp and humidity sensors to obtain desired successively lower wet bulb temp (using a psychromatric chart may be helpful), and observe condenser water supply temp | | | | 5 |
| 6 | Record simulated outdoor conditions:<br>Dry bulb temp, F / Humidity / Wet bulb temp, F<br>_____ _____ _____<br>_____ _____ _____<br>_____ _____ _____ | | | | 6 |

COMMENTS:______________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

TEST WORK SHEET WS 6B-16 -- EMCS APPLICATION SOFTWARE TEST, CONDENSER WATER TEMPERATURE RESET continued

Page 2

Supplier________________ Date__________

EMCS system model________

HVAC system______________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7 | Verify that condenser water temp decreases | | | | 7 |
| 8 | Manipulate simulators to simulate wet bulb temp 3 F below specified low limit | | | | 8 |
| 9 | Record simulated outdoor conditions:<br>Dry bulb temp _____ F<br>Relative Humidity _____ %<br>Wet bulb _____ F | | | | 9 |
| 10 | Verify that condenser water does not drop below specified low limit | | | | 10 |
| 11 | Restore temp and humidity sensors | | | | 11 |
| 12 | Test conclusion | | | | 12 |

COMMENTS:____________________________________________

____________________________________________

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## 7.1 INSPECTION CHECK LIST CL 7A-1 -- FIRE SAFETY IN HVAC SYSTEMS

Date___________
Inspection agent_____________

| NO. | DESCRIPTION | YES | NO | REMARKS |
|---|---|---|---|---|
| **General:** | | | | |
| 1 | All materials in plenums appropriate | | | |
| 2 | Air filters appropriate | | | |
| 3 | Fan inlets protected by screens | | | |
| 4 | Heating equipment installation appropriate | | | |
| 5 | Cooling equipment installation appropriate | | | |
| 6 | Manual controls installed | | | |
| 7 | Automatic controls installed | | | |
| **Ductwork:** | | | | |
| 1 | Duct material appropriate | | | |
| 2 | Duct installation appropriate | | | |
| 3 | Duct connectors appropriate | | | |
| 4 | Duct coverings appropriate | | | |
| 5 | Duct linings appropriate | | | |
| **Duct access and inspection provisions:** | | | | |
| 1 | Access at all required locations | | | |
| 2 | Access properly identified | | | |
| **Dampers:** | | | | |
| 1 | Fire dampers located where required | | | |
| 2 | Fire dampers of appropriate rating | | | |
| 3 | Fire dampers installed appropriately | | | |
| 4 | Ceiling dampers located where required | | | |
| 5 | Ceiling dampers of appropriate rating | | | |
| 6 | Ceiling dampers installed appropriately | | | |
| 7 | Smoke dampers located where required | | | |
| 8 | Smoke dampers of appropriate rating | | | |
| 9 | Smoke dampers installed appropriately | | | |
| 10 | Combination fire and smoke dampers located where required | | | |
| 11 | Combination fire and smoke dampers of appropriate rating | | | |
| 12 | Combination fire and smoke dampers installed appropriately | | | |

COMMENTS:________________________________________________________

## 7.2 INSPECTION CHECK LIST CL 7A-2 -- FIRE SAFETY CONTROLS IN HVAC SYSTEMS WITHOUT SMOKE CONTROL CAPABILITIES

Date___________
Inspection agent_____________

| NO. | DESCRIPTION | YES | NO | REMARKS |
|---|---|---|---|---|
| | **Manual shutdown:** | | | |
| 1 | Appropriate fans stopped and started | | | |
| 2 | Appropriate smoke dampers fully and tightly closed | | | |
| | **Automatic shutdown by return detector:** | | | |
| 1 | Appropriate fans stopped and started | | | |
| 2 | Appropriate smoke dampers fully and tightly closed | | | |
| | **Automatic shutdown by supply detector:** | | | |
| 1 | Appropriate fans stopped and started | | | |
| 2 | Appropriate smoke dampers fully and tightly closed | | | |
| | **Automatic shutdown by detector system:** | | | |
| 1 | Appropriate fans stopped and started | | | |
| 2 | Appropriate smoke dampers fully and tightly closed | | | |

COMMENTS:________________________________________________

_________________________________________________________

_________________________________________________________

## 7.3 TEST WORK SHEET WS 7B-1 -- ZONED SMOKE CONTROL SYSTEM

Page 1

Date____________

Test agent______________

### NORMAL OPERATION TEST

| Doors in barriers of smoke control zone | Pressure Difference (inches water gage) | Flow Direction: From Zone | To Zone |
|---|---|---|---|
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TEST WORK SHEET WS 7B-1 -- ZONED SMOKE CONTROL SYSTEM (continued)

Page 2

Smoke Control Zone No.________
Date__________
Test agent____________

SMOKE MODE TEST

| NO. | YES | NO | REMARKS |
|---|---|---|---|
| 1. Fans operating appropriately | | | |
| 2. Smoke dampers in required position | | | |
| 3. Pass feedback test | | | |

| Doors in Boundary of Smoke Control Zone | Pressure Difference (inches of water gage) |
|---|---|
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COMMENTS:________________________________________
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TEST WORK SHEET WS 7B-1 -- ZONED SMOKE CONTROL SYSTEM - DUCT MOUNTED DETECTOR (continued) Page 3

Smoke Control Zone No.__________
Smoke Detector No.__________
Sensitivity Setting__________
Location of Detector__________
Date__________
Test agent__________

DUCT MOUNTED DETECTOR SMOKE MODE TEST

| NO. | YES | NO | REMARKS |
|---|---|---|---|
| 1. Fans operating appropriately | | | |
| 2. Smoke dampers in required position | | | |
| 3. Smoke detector in required position | | | |
| 4. Velocity pressure meets requirements | | | |
| 5. Smoke detector alarms in allowable time | | | |
| 6. Post-alarm operating sequence is proper | | | |

Air flow in duct _______ cfm
Duct size _______
Minimum specified velocity pressure _____ w.c.
Elasped time from smoke discharge to detector alarm _____ sec

Note: Repeat test for each duct detector

COMMENTS:______________________________________________

## 7.4 TEST WORK SHEET WS 7C-1 -- PRESSURIZED STAIRWELL SYSTEM

Page 1

Doors Open__________________

____________________________

____________________________

Stairwell No._______________

Date____________

Test agent______________

PRESSURE DIFFERENCE MEASUREMENTS

| Doors in Pressurized Stairwell | Pressure Difference (inches water gage) |
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TEST WORK SHEET WS 7C-1 -- PRESSURIZED STAIRWELL SYSTEM (Continued)
Page 2

Date____________
Test agent_____________
Stairwell No.__________

FLOW DIRECTION INDICATION

| Doors Open in Pressurized Stairwell | Flow Direction: From Stair | To Stair |
|---|---|---|
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COMMENTS:

## 8.1 INSPECTION CHECK LIST CL 8A-1 -- ROOFTOP AIR CONDITIONING UNIT

Page 1

ACU no.____________________ Date__________
Make & model________________ Inspection agent________________

Serial no.__________________ Commissioning team_______________
Heating media: steam___, water___, _______________
elec___, gas___ (check one) _______________
Stage of cooling: 1___, 2___, 3___,4___.

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| General: | | | | | |
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify unit model with submittals | | | | 3 |
| 4 | Component service space adequate | | | | 4 |
| 5 | Air filter replacement space adequate | | | | 5 |
| 6 | Other access space adequate (headroom, access doors, etc) | | | | 6 |
| 7 | Equipment space clean. no fire hazards | | | | 7 |
| 8 | Proper vibration unit installation | | | | 8 |
| 9 | Pipe fittings and accessories complete | | | | 9 |
| 10 | Check valves and flow switches, flow direction correct | | | | 10 |
| 11 | Pipes supported properly | | | | 11 |
| 12 | Protection shields for motor and belts | | | | 12 |
| 13 | Alignment of motor driven components | | | | 13 |
| 14 | Belt tightness satisfactory | | | | 14 |
| 15 | Lubrication complete and proper | | | | 15 |
| 16 | Correct refrigerant kind | | | | 16 |
| 17 | Correct refrigerant level | | | | 17 |
| 18 | Compressor oil filter clean and proper | | | | 18 |
| 19 | Correct compressor oil level:<br>Before operation _____<br>During operation _____ | | | | 19 |
| 20 | Cramkcase heater installed correctly | | | | 20 |
| 21 | Crankcase heater on when unit off | | | | 21 |
| 22 | Thermometers complete | | | | 22 |
| 23 | Pressure gages complete | | | | 23 |
| 24 | Flow meters meet installation requirements | | | | 24 |
| 25 | Electric wiring installation proper | | | | 25 |
| 26 | Elec motors & components grounded properly | | | | 26 |
| 27 | All electric connections tight | | | | 27 |

COMMENTS:________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

INSPECTION CHECK LIST CL 8A-1 -- ROOFTOP AIR CONDITIONING HANDLING UNIT (continued) Page 2

ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 28 | Size of overcurrent heater in motor starter | | | | 28 |
| 29 | Test run motors for direction of rotation | | | | 29 |
| 30 | Thermal insulation complete and no damage | | | | 30 |
| 31 | Surface paint complete | | | | 31 |
| 32 | Equipment labels complete and legible | | | | 32 |
| 33 | Control air pressure correct (Pneumatic control) | | | | 33 |
| 34 | No excessive air leakage from unit | | | | 34 |
| 35 | No unusual noise & vibration when running | | | | 35 |
| 36 | Automatic control instruments installed as specified | | | | 36 |
| 37 | Proper calibration of instrumentation | | | | 37 |
| 38 | Unit location proper (relative to roof structure) | | | | 38 |
| 39 | Roof curb leveling correct | | | | 39 |
| 40 | Roof curb weatherproofing proper | | | | 40 |
| 41 | Sealing between roof curb and unit proper | | | | 41 |
| 42 | All roof sleeves sealed correctly: | | | | 42 |
| | Ducts | | | | |
| | Pipes | | | | |
| | Wires | | | | |
| | Conduits | | | | |
| Fan: | | | | | |
| 1 | Housing access doors and latchs tight | | | | 1 |
| 2 | Grease or oil tubes for bearings proper | | | | 2 |
| 3 | No need removing belt guard for oiling or speed check | | | | 3 |
| 4 | Fan running steadily | | | | 4 |
| 5 | Fans with inlet vanes or outlet dampers: | | | | 5 |
| 5a | Damper linkage no excessive play | | | | 5a |
| 5b | Damper closes tight | | | | 5b |
| 5c | Direction of inlet damper blade proper | | | | 5c |
| 5d | Inlet dampers for double inlet fan proper | | | | 5d |
| 6 | Protective hood over motor and belt for outdoor installation | | | | 6 |
| 7 | Inlet and outlet wire protection for fan without duct connection | | | | 7 |
| 8 | Flexible connections between fan and ducts | | | | 8 |

COMMENTS:______________________________________________

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INSPECTION CHECK LIST CL 8A-1 -- ROOFTOP AIR CONDITIONING UNIT (continued)
Page 3

ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | **Coils:** | | | | |
| 1 | No damage to heat transfer fins | | | | 1 |
| 1a | Heating coil | | | | 1a |
| 1b | Cooling coil | | | | 1b |
| 2 | Coil tubes pitch correctly | | | | 2 |
| 2a | Heating coil | | | | 2a |
| 2b | Cooling coil | | | | 2b |
| 3 | No air bypass between coil and casing | | | | 3 |
| 3a | Heating coil | | | | 3a |
| 3b | Cooling coil | | | | 3b |
| 4 | Cooling coil drain pans and pipes | | | | 4 |
| 5 | Coil pipe fittings and accessories | | | | 5 |
| 5a | Shut-off valves | | | | 5a |
| 5b | Strainers | | | | 5b |
| 5c | Air vents | | | | 5c |
| 5d | Sensor and thermometer wells | | | | 5d |
| 5e | Balancing devices | | | | 5e |
| 5f | Drain | | | | 5f |
| 5g | Others | | | | 5g |
| 6 | Flow measuring device | | | | 6 |
| 6a | Upstream pipe length or flow straightener | | | | 6a |
| 6b | Downstream pipe length | | | | 6b |
| 6c | Meter connection and valves complete | | | | 6c |
| 6d | Tag with flow rate information | | | | 6d |
| 7 | Condensate pipe at steam trap not over 200 F when control valve is open (for low pressure steam only) | | | | 7 |
| | **Air filters:** | | | | |
| 1 | Filter frame securely anchored to casing | | | | 1 |
| 2 | No air leakage around filter frame | | | | 2 |
| 3 | No air leakage between filter bank and unit casing | | | | 3 |
| 4 | New (clean) filter media | | | | 4 |
| 5 | Filter gage pressure sensing tip proper | | | | 5 |
| 6 | Inclined manometer gage installation | | | | 6 |

COMMENTS:______________________________________________

INSPECTION CHECK LIST CL 8A-1 -- ROOFTOP AIR CONDITIONING UNIT (continued)
Page 4

AHU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 7 | Check auto renewable filter advancing mechanism | | | | 7 |
| 7a | Motor | | | | 7a |
| 7b | Driving train | | | | 7b |
| 7c | Timer | | | | 7c |
| 7d | Pressure sensing | | | | 7d |
| 7e | Overriding operation | | | | 7e |
| 7f | Control operation | | | | 7f |
| 8 | Filter replacement space adequate | | | | 8 |
| 9 | Spare filters to meet specifications | | | | 9 |
| | **Air dampers:** | | | | |
| 1 | Blade arrangement: parallel_____ opposed _____ | | | | 1 |
| 2 | Blade edge sealing | | | | 2 |
| 3 | Bearings as specified | | | | 3 |
| 4 | Actuator linkage and blade movement | | | | 4 |
| 5 | Access door for dampers in duct | | | | 5 |
| | **Air louvers:** | | | | |
| 1 | Material | | | | 1 |
| 2 | Construction | | | | 2 |
| 3 | Dimensions | | | | 3 |
| 4 | Screen | | | | 4 |
| | **Casings:** | | | | |
| 1 | Rigidity | | | | 1 |
| 2 | Integraty | | | | 2 |
| 3 | Access doors: | | | | 3 |
| 3a | Size | | | | 3a |
| 3b | Gasket | | | | 3b |
| 3c | latches | | | | 3c |
| 4 | Flexible connections between unit and ducts | | | | 4 |

COMMENTS:______________________________________________________________
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INSPECTION CHECK LIST CL 8A-1 -- ROOFTOP AIR CONDITIONING UNIT (continued)
Page 5

AHU no.__________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | Thermal and acoustic insulation: | | | | |
| 1 | No damages and omissions | | | | 1 |
| 2 | Material | | | | 2 |
| 3 | Thickness | | | | 3 |
| 5 | Vapor barrier material and sealing | | | | 5 |
| 6 | Surface finishing | | | | 6 |
| | Automatic controls: | | | | |
| 1 | Give general check on control installations against contract documents and submittals | | | | 1 |
| 2 | Observe general operation. Any obvious malfunction, incorrect calibrations, or incorrct settings and ranges? | | | | 2 |
| 3 | Are mercury switches leveled correctly? | | | | 3 |
| 4 | Check valves for correct closing | | | | 4 |
| 5 | Valves and linkages installed securely | | | | 5 |
| 6 | Valve linkages travel freely | | | | 6 |
| 7 | Check dampers for correct closing | | | | 7 |
| 8 | Dampers and linkages installed securely | | | | 8 |
| 9 | Damper linkages travel freely | | | | 9 |
| 10 | Safety features (coil freeze protection, etc.) installed correctly | | | | 10 |
| 11 | Interlocking installed correctly | | | | 11 |
| 12 | For controls interfacing with pneumatic building system, check interfacing devices | | | | |
| 13 | For electrcal and electronic systems: | | | | 13 |
| 13a | Wire connections tight | | | | 13a |
| 13b | No broken wires | | | | 13b |
| 13c | No rust, corrosion or film on wire terminals | | | | 13c |
| 13d | Correct voltage on power supply | | | | 13d |
| 13e | Signal wires shielded correctly | | | | 13e |
| 13f | Shielding terminated at one end only | | | | 13f |

COMMENTS:__________________________________________________

## 8.2 INSPECTION CHECK LIST CL 8A-2 -- COMPUTER ROOM AIR CONDITIONING UNIT

Page 1

ACU no.____________________ Date__________

Make & model________________ Inspection agent__________________

Serial no._________________ Commissioning team_________________

Electric reheat: yes___, no___ (check one)

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| General: | | | | | |
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify unit model with submittals | | | | 3 |
| 4 | Component service space adequate | | | | 4 |
| 5 | Air filter replacement space adequate | | | | 5 |
| 6 | Other access space adequate (headroom, access doors, etc) | | | | 6 |
| 7 | Equipment space clean. no fire hazards | | | | 7 |
| 8 | Proper vibration unit installation | | | | 8 |
| 9 | Pipe fittings and accessories complete | | | | 9 |
| 10 | Check valves and flow switches. Flow direction correct | | | | 10 |
| 11 | Pipes supported properly | | | | 11 |
| 12 | Protection shields for motor and belts | | | | 12 |
| 13 | Alignment of motor driven components | | | | 13 |
| 14 | Belt tightness | | | | 14 |
| 15 | Lubrication complete and proper | | | | 15 |
| 16 | Correct refrigerant kind | | | | 16 |
| 17 | Correct refrigerant level | | | | 17 |
| 18 | Compressor oil filter clean and proper | | | | 18 |
| 19 | Correct compressor oil level:<br>Before operation _____<br>During operation _____ | | | | 19 |
| 20 | Crankcase heater installed correctly | | | | 20 |
| 21 | Crankcase heater on when unit off | | | | 21 |
| 22 | Thermometers complete | | | | 22 |
| 23 | Pressure gages complete | | | | 23 |
| 24 | Flow meters meet installation requirements | | | | 24 |
| 25 | Electric wiring installation proper | | | | 25 |
| 26 | Elec motors & components grounded properly | | | | 26 |
| 27 | All electric connections tight | | | | 27 |

COMMENTS:________________________________________________________

INSPECTION CHECK LIST CL 8A-2 -- COMPUTER ROOM AIR CONDITIONING UNIT (continued)



ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 28 | Size of overcurrent heater in motor starter | | | | 28 |
| 29 | Test run motors for direction of rotation | | | | 29 |
| 30 | Thermal insulation complete and no damage | | | | 30 |
| 31 | Surface paint complete | | | | 31 |
| 32 | Equipment labels complete and legible | | | | 32 |
| 33 | No excessive air leakage from unit | | | | 33 |
| 34 | No unusual noise & vibration when running | | | | 34 |
| 35 | Automatic control instruments installed as specified | | | | 35 |
| 36 | Proper calibration of instrumentation | | | | 36 |
| Fan: | | | | | |
| 1 | Housing access doors and latchs tight | | | | 1 |
| 2 | Grease or oil tubes for bearings proper | | | | 2 |
| 3 | No need removing belt guard for oiling or speed check | | | | 3 |
| 4 | Fan running steadily | | | | 4 |
| 5 | Fans with inlet vanes or outlet dampers: | | | | 5 |
| 5a | Damper linkage no excessive play | | | | 5a |
| 5b | Damper closes tight | | | | 5b |
| 5c | Direction of inlet damper blade proper | | | | 5c |
| 5d | Inlet dampers for double inlet fan proper | | | | 5d |
| 6 | Flexible connections between fan and ducts | | | | 6 |
| Coils: | | | | | |
| 1 | No damage to heat transfer fins | | | | 1 |
| 2 | Coil tubes pitch correctly | | | | 2 |
| 3 | No air bypass between coil and casing | | | | 3 |
| 4 | Cooling coil drain pans and pipes | | | | 4 |
| 5 | Coil pipe fittings and accessories | | | | 5 |
| 5a | Shut-off valves | | | | 5a |
| 5b | Strainers | | | | 5b |
| 5c | Air vents | | | | 5c |
| 5d | Thermometer wells | | | | 5d |
| 5e | Balancing devices | | | | 5e |
| 5f | Drain | | | | 5f |
| 5g | Others | | | | 5g |
| 6 | Flow measuring device | | | | 6 |
| 6a | Upstream pipe length or flow straightener | | | | 6a |
| 6b | Downstream pipe length | | | | 6b |
| 6c | Meter connection and valves complete | | | | 6c |
| 6d | Tag with flow rate information | | | | 6d |

COMMENTS:______________________________________________

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INSPECTION CHECK LIST CL 8A-2 -- COMPUTER ROOM AIR CONDITIONING UNIT (continued)

Page 3

ACU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | **Air filters:** | | | | |
| 1 | Filter frame anchored to casing securely | | | | 1 |
| 2 | No air leakage around filter frame | | | | 2 |
| 3 | No air leakage between filter bank and unit casing | | | | 3 |
| 4 | New (clean) filter media | | | | 4 |
| 5 | Filter gage pressure sensing tip proper | | | | 5 |
| 6 | Inclined manometer gage installation | | | | 6 |
| 7 | Filter replacement spece adequate | | | | 7 |
| 8 | Spare filters | | | | 8 |
| | **Air dampers:** | | | | |
| 1 | Blade arrangement: parallel_____ opposed _____ | | | | 1 |
| 2 | Blade edge sealing | | | | 2 |
| 3 | Bearings as specified | | | | 3 |
| 4 | Actuator linkage and blade movement | | | | 4 |
| 5 | Access door for dampers in duct | | | | 5 |
| | **Casings:** | | | | |
| 1 | Rigidity | | | | 1 |
| 2 | Integraty | | | | 2 |
| 3 | Access doors: | | | | 3 |
| 3a | Size | | | | 3a |
| 3b | Gasket | | | | 3b |
| 3c | latches | | | | 3c |
| 4 | Flexible connections between unit and ducts | | | | 4 |
| | **Thermal and acoustic insulation:** | | | | |
| 1 | No damages and omissions | | | | 1 |
| 2 | Material | | | | 2 |
| 3 | Thickness | | | | 3 |
| 5 | Vapor barrier material and sealing | | | | 5 |
| 6 | Surface finishing | | | | 6 |

COMMENTS:____________________________________________

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INSPECTION CHECK LIST CL 8A-2 -- COMPUTER ROOM AIR CONDITIONING UNIT (continued)

Page 4

AHU no.____________________ Date__________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| | Automatic controls: | | | | |
| 1 | Give general check on control installations against contract documemts and submittals | | | | 1 |
| 2 | Observe general operation. Any obvious malfunction, incorrect calibrations, or incorrct settings and ranges? | | | | 2 |
| 3 | Are mercury switches leveled correctly? | | | | 3 |
| 4 | Check valves for correct closing | | | | 4 |
| 5 | Valves and linkages installed securely | | | | 5 |
| 6 | Valve linkages travel freely | | | | 6 |
| 7 | Check dampers for correct closing | | | | 7 |
| 8 | Dampers and linkages installed securely | | | | 8 |
| 9 | Damper linkages travel freely | | | | 9 |
| 10 | Interlocking installed correctly | | | | 11 |
| 11a | Control wire connections tight | | | | 11a |
| 11b | No broken control wires | | | | 11b |
| 11c | No rust, corrosion or film on wire terminals | | | | 11c |
| 11d | Correct voltage on power supply | | | | 11d |
| 11e | Signal wires shielded correctly | | | | 11e |
| 11f | Shielding grounded at one end only | | | | 11f |
| 12 | Check operation of indicating lights | | | | 12 |
| 13 | Check operation of audible alarms | | | | 13 |
| 14 | Check dehumidifier operation for units with variable air flow rates when dehumidify is in operation | | | | 14 |
| 15 | Check operation of underfloor water detection system | | | | 15 |
| 16 | Check operation of unit fire detection system | | | | 16 |
| 17 | Check operation of unit smoke system | | | | 17 |

COMMENTS:________________________________________

## 8.3 INSPECTION CHECK LIST CL 8A-3 -- PACKAGED TERMINAL AIR-CONDITIONER

ACU no.____________________ Date__________

Make & model________________ Inspection agent_________________

Serial no.__________________ Commissioning team_______________

Electric heat: yes___, no___ (check one) _______________ _______________

| NO. | DESCRIPTION | YES | NO | REMARKS | NO. |
|---|---|---|---|---|---|
| 1 | Operation and maintenance manuals complete | | | | 1 |
| 2 | General appearances, no apparent damage | | | | 2 |
| 3 | Verify unit model with submittals | | | | 3 |
| 4 | Electric wiring installation proper | | | | 4 |
| 5 | Wire connections tight | | | | 5 |
| 6 | No broken control wires | | | | 6 |
| 7 | No rust, corrosion or film on wire terminals | | | | 7 |
| 8 | Elec motors & components grounded properly | | | | 8 |
| 9 | All electric connections tight | | | | 9 |
| 10 | Thermal insulation complete and no damage | | | | 10 |
| 11 | Surface finishing of thermal insulation as required | | | | 11 |
| 12 | Surface paint complete | | | | 12 |
| 13 | Eequipment labels complete and legible | | | | 13 |
| 14 | No unusual noise & vibration when running | | | | 14 |
| 15 | Proper calibration of thermostat | | | | 15 |
| 16 | No damage to heat transfer fins | | | | 16 |
| 17 | No air leakage around filter frame | | | | 17 |
| 18 | New (clean) filter media | | | | 18 |
| 19 | Spare filters provided as required | | | | 19 |
| 20 | Observe general operation of unit | | | | 20 |
| 21 | Turn unit control knob at all stops and thermostat settings to verify unit operation:<br>fan (on/off)<br>compressor (on/off)<br>damper (open/close, closing tight)<br>heating element (on/off)<br>indicating lights | | | | 21 |
| 22 | Inspect wall sleeve for proper installation | | | | 22 |
| 23 | Inspect around wall sleeve for seals | | | | 23 |
| 24 | Inspect unit condensate disposing system | | | | 24 |

COMMENTS:______________________________________________

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## 8.4 TEST WORK SHEET WS 8B-1 -- INSTRUMENT CALIBRATION FOR UNITARY AIR CONDITIONING UNIT

Page 1

Date__________
Test agent______________________
Commissioning team______________
______________
______________

Notes for using form:

1. This work sheet is used for calibrating sensing devices and instruments used in recording performance tests. Calibration of indicating devices for equipment operations are covered under equipment test work sheets.
2. Standard instruments used for calibrating sensing devices must have valid calibration. Record calibration data in Block A.
3. All instruments and sensing devices must be calibrated on bench or in field with standard instruments. At leasttwo points covering the entire range of normal operation should be calibrated. This work sheet lists recommended calibration points. After final calibration, record data in Block B.

A. Standard instruments data (copy from standard instrument records):

| | type | Make, model & serial no. | Calib. Date | Calib. by (organization) |
|---|---|---|---|---|
| Temperature | | | | |
| Humidity | | | | |
| Pressure | | | | |
| Power | | | | |
| Others | | | | |

B. Final calibration data (set-temperature listed below may be changed according to application):

| No. | Instrument or sensing Device | Low point: Approx. Calib Point | Low point: Std Inst Reading | Low point: Final Calib Reading | High point: Approx. Calib Point | High point: Std Inst Reading | High point: Final Calib Reading | No. |
|---|---|---|---|---|---|---|---|---|
| Temperature, F: | | | | | | | | |
| 1 | Water (for condenser, steam, condensate, and hot water) | 32 | | | 200 | | | 1 |
| 2 | Low pressure steam | 200 | | | 300 | | | 2 |
| 3 | Air | 32 | | | 150 | | | 3 |

TEST WORK SHEET WS 8B-1 -- INSTRUMENT CALIBRATION FOR UNITARY AIR CONDITIONING UNIT continued

Page 2

Date__________

| No. | Instrument or sensing Device | Low point: Approx. Calib Point | Low point: Std Inst Reading | Low point: Final Calib Reading | High point: Approx. Calib Point | High point: Std Inst Reading | High point: Final Calib Reading | No. |
|---|---|---|---|---|---|---|---|---|
| Humidity: | | | | | | | | |
| 4 | Relative humidity, % | 30#1 | | | 90#1 | | | 4 |
| 5 | Dew point temp, F | 35 | | | 75 | | | 5 |
| 6 | Wet bulb temp, F | 35#2 | | | 75#2 | | | 6 |
| Flow: | | | | | | | | |
| 7 | Water and steam, gpm | #3 | | | #4 | | | 7 |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |
| 8 | Air velocity, fpm, Also see #5 | 0 | | | 1000 | | | 8 |
| Pressure: | | | | | | | | |
| 9 | Air, in. w.c. | 0 | | | #6 | | | 9 |
| Other devices: | | | | | | | | |
| | a.__________ | | | | | | | |
| | b.__________ | | | | | | | |
| | c.__________ | | | | | | | |

Notes:

#1 Within a dry bulb temperature range of 10 - 100 F
#2 Within a dry bulb temperature range of 35 - 100 F
#3 25% below specified values
#4 25% above specified values
#5 This is for velocity type instrumsnts, see pressure calibration for pressure sensing devices (pitot)
#6 Expected highest pressure or 5 in. w.c. whicherever is higher

Comments:______________________________________________

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## 8.5 TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST

Page 1

AH unit no.________________ Date__________

Make & model________________ Inspection agent________________

Serial no.________________ Commissioning team________________

Type: (check one) Rooftop___ ________________

Computer room___ ________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Supply air fan and return air fan for constant air volume system: | | | | |
| 1 | Set and lock outside air damper at minimum position | | | | 1 |
| 2 | Set and lock return air damper | | | | 2 |
| 3 | Set and lock relief air damper | | | | 3 |
| 4 | Measure barometric pressure _____ in.Hg | | | | 4 |
| 5 | Measure electric service voltage: | | | | 5 |
| 5a | Supply fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5a |
| 5b | Return fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5b |

COMMENTS:________________________________________

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TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued
Page 2

AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6 | Measure supply air fan performance: (6b through 6g not required for units without external ductwork) | | | | 6 |
| 6a | Air flow rate, see Test Work Sheet WS 2C-1 or 2C-2 _____cfm (*_____cfm) | | | | 6a |
| 6b | Total p at fan inlet_____ in.w.c. | | | | 6b |
| 6c | Static p at fan inlet_____in.w.c. | | | | 6c |
| 6d | Total p at fan outlet_____in.w.c. | | | | 6d |
| 6e | Static p at fan outlet_____in.w.c. | | | | 6e |
| 6f | Velocity p at fan inlet_____in.w.c. | | | | 6f |
| 6g | Velocity p at fan outlet_____in.w.c. | | | | 6g |
| 6h | Fan speed _____ rpm | | | | 6h |
| 6i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 6i |
| 7 | Check 10% of supply air outlets: | | | | 7 |
| 7a | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 7a |
| 7b | Calculate error (1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 7b |
| 7c | If 10% of 7b is outside +/- 10%, check another 10% of supply outlets: | | | | 7c |

COMMENTS:____________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued



AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 7d | Room_____, measured _____cfm (* cfm) | | | | 7d |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| | Room_____, measured _____cfm (* cfm) | | | | |
| 7e | Calculate error (1 - measured/specified supply) x 100% | | | | 7e |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| | Room_____, Error = _____ % | | | | |
| 8 | If 10% of the outlets measured in 7b & 7e are outside +/- 15%, rebalance system. | | | | 8 |
| 9 | Total air flow rate of measured outlets______cfm (7a & 7d) | | | | 9 |
| 10 | Total air flow rate of specified_______cfm (7a & 7d) | | | | 10 |
| 11 | Calculate error (1 - measured/specified supply) x 100% = _____% | | | | 11 |
| 12 | If error in 11 is outside +/- 10%, rebalance system. | | | | 12 |
| 13 | Measure return air fan performance: | | | | 13 |
| 13a | Air flow rate, use Test Work Sheet WS 2C-1 or 2C-2 (_____cfm) (*_____cfm) | | | | 13a |
| 13b | Total p at fan inlet_____ in.w.c. | | | | 13b |
| 13c | Static p at fan inlet_____in.w.c. | | | | 13c |
| 13d | Total p at fan outlet_____in.w.c. | | | | 13d |
| 13e | Static p at fan outlet_____in.w.c. | | | | 13e |
| 13f | Velocity p at fan inlet_____in.w.c. | | | | 13f |
| 13g | Velocity p at fan outlet_____in.w.c. | | | | 13g |
| 13h | Fan speed _____ rpm | | | | 13h |

COMMENTS:______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued

Page 4

AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 13i |
| 14 | Set outside air damper to 100% OA | | | | 14 |
| 15 | Set return air damper | | | | 15 |
| 16 | Set relief air damper | | | | 16 |
| 17 | Measure supply fan motor current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 17 |
| 18 | Measure return fan motor current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 18 |
| 19 | Restore damper controls | | | | 19 |
| 20 | Check 10% of return air outlets: | | | | 20 |
| 20a | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 20a |
| 20b | Calculate error<br>(1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 20b |

COMMENTS:______________________________________________

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TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued Page 5

AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 20c | If 10% of 7b is outside +/- 10%, check another 10% of supply outlets: | | | | 20c |
| 20d | Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm)<br>Room_____, measured _____cfm (* cfm) | | | | 20d |
| 20e | Calculate error<br>(1 - measured/specified supply) x 100%<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ %<br>Room_____, Error = _____ % | | | | 20e |
| 21 | If 10% of the outlets measured in 7b & 7e are outside +/- 15%, rebalance system. | | | | 21 |
| 22 | Total air flow rate of measured outlets______cfm (7a & 7d) | | | | 22 |
| 23 | Total air flow rate of specified_______cfm (7a & 7d) | | | | 23 |
| 24 | Calculate error<br>(1 - measured/specified supply) x 100% = _____% | | | | 24 |
| 25 | If error in 11 is outside +/- 10%, rebalance system. | | | | 25 |

COMMENTS:______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued
Page 6

AH unit no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Supply air fan and return air fan for variable air volume system: | | | | |
| 1 | Set and lock outside air damper at 100% OA position | | | | 1 |
| 2 | Set and lock return air damper | | | | 2 |
| 3 | Set and lock relief air damper | | | | 3 |
| 4 | Measure barometric pressure _____ in.Hg | | | | 4 |
| 5 | Measure electric service voltage: | | | | 5 |
| 5a | Supply fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5a |
| 5b | Return fan motor:<br>Phases 1-2 _____ V<br>Phases 2-3 _____ V<br>Phases 3-1 _____ V | | | | 5b |
| 6 | Select 10% of VAV boxes: | | | | |
| 6a | Lower rm. thermostats 5 F to measure max. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 6a |
| 6b | Raise rm. thermostats 10 F to measure min. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 6b |

COMMENTS:____________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued



AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 6c | Calculate error:<br>(1 - measured/specified supply) x 100%<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min) | | | | 6c |
| 7 | If 10% of VAV boxes measured are outside +/- 10%, check another 10% of boxes: | | | | |
| 7a | Lower rm. thermostats 5 F to measure max. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 7a |
| 7b | Raise rm. thermostats 10 F to measure min. flow, note operation of reheat coil/recirculating fan:<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm)<br>Box #_____, measured _____cfm (* cfm) | | | | 7b |
| 7c | Calculate error:<br>(1 - measured/specified supply) x 100%<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min)<br>Box #_____, Error = __ %(max); Error = __%(min) | | | | 7c |

COMMENTS:_____________________________________________

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_____________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued

Page 8

AH unit no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | If 10% of the VAV boxes measured in 6 & 7 are outside +/- 15%, rebalance system. | | | | 8 |
| 9 | Total air flow rate of measured boxes______cfm (max) | | | | 9 |
| 10 | Total air flow rate of specified_______cfm (max) | | | | 10 |
| 11 | Total air flow rate of measured boxes______cfm (min) | | | | 11 |
| 12 | Total air flow rate of specified_______cfm (min) | | | | 12 |
| 13 | Calculate error:<br>(1 - measured/specified supply) x 100% = __% (max)<br>(1 - measured/specified supply) x 100% = __% (min) | | | | 13 |
| 14 | If error in 13 is outside +/- 10%, rebalance system. | | | | 14 |
| 15 | Measure and record duct static pressure at fan static pressure sensor locations:<br>Sensor #1 measured _____"w.c. (shown on control dwg _____"w.c.)<br>Sensor #2 measured _____"w.c. (shown on control dwg _____"w.c.)<br>Sensor #3 measured _____"w.c. (shown on control dwg _____"w.c.) | | | | 15 |
| 16 | Measure duct static pressure at branch ducts before last VAV boxes:<br>Branch 1 measured _____"w.c.<br>Branch 2 measured _____"w.c.<br>Branch 3 measured _____"w.c.<br>Branch 4 measured _____"w.c.<br>Branch 5 measured _____"w.c. | | | | 16 |
| 17 | Specified minimum static pressure *_____"w.c. | | | | 17 |
| 18 | Any branch must be:<br>*_____w.c. < measured press < measured press + 0.2"w.c. | | | | 18 |

COMMENTS:_______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, AIR FLOW RATE TEST continued



AH unit no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 19 | Record supply air fan performance: | | | | 19 |
| 19a | Air flow rate, see Test Work Sheet WS 2C-1 or 2C-2 (_____cfm) (*_____cfm) | | | | 19a |
| 19b | Total p at fan inlet_____ in.w.c. | | | | 19b |
| 19c | Static p at fan inlet_____in.w.c. | | | | 19c |
| 19d | Total p at fan outlet_____in.w.c. | | | | 19d |
| 19e | Static p at fan outlet_____in.w.c. | | | | 19e |
| 19f | Velocity p at fan inlet_____in.w.c. | | | | 19f |
| 19g | Velocity p at fan outlet_____in.w.c. | | | | 19g |
| 19h | Fan speed _____ rpm | | | | 19h |
| 19i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 19i |
| 20 | Measure return air fan performance: | | | | 20 |
| 20a | Air flow rate, see Test Work Sheet WS 2C-1 or 2C-2 (_____cfm) (*_____cfm) | | | | 20a |
| 20b | Total p at fan inlet_____ in.w.c. | | | | 20b |
| 20c | Static p at fan inlet_____in.w.c. | | | | 20c |
| 20d | Total p at fan outlet_____in.w.c. | | | | 20d |
| 20e | Static p at fan outlet_____in.w.c. | | | | 20e |
| 20f | Velocity p at fan inlet_____in.w.c. | | | | 20f |
| 20g | Velocity p at fan outlet_____in.w.c. | | | | 20g |
| 20h | Fan speed _____ rpm | | | | 20h |
| 20i | Motor current and name plate FL current:<br>Lead 1 _____amp (* amp)<br>Lead 2 _____amp (* amp)<br>Lead 3 _____amp (* amp) | | | | 20i |
| 21 | Restore damper controls | | | | 21 |

COMMENTS:______________________________________________

______________________________________________

______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HEATING CAPACITY TEST continued

Page 10

AH unit no._____________ Date__________
Heating medium: Steam___ Inspection agent________________

(check one) Water___ Commissioning team_______________
Elec____ _______________
Gas_____ _______________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| | Heating capacity: | | | | |
| 1 | Air flow rate (from air flow rate test, WS-2,page 2) _____ cfm | | | | 1 |
| 2 | Measure entering air temp apply false load if needed (*_____ F) average temp _____ F | | | | 2 |
| 3 | Measure & adjust ent w temp to within 1 F of specified (water coil only) (*_____ F) _____ F | | | | 3 |
| 4 | Measure & adjust steam temp & pressure (steam coil only) to within 1 psi of specified (*_____ psi) _____ psi _____ F Is steam saturated? | | | | 4 |
| 5 | Measure and adjust water or steam flow rate to within 3% of specified (water or steam coil only) | | | | 5 |
| 6 | Disable control of test coil (water or steam coil only) | | | | 6 |
| 7 | Check electric coil is energized (electric coil only) | | | | 7 |
| 8 | Check gas burner is on (gas unit only) | | | | 8 |
| 9 | Run unit for at least 10 minutes | | | | 9 |

COMMENTS:____________________________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HEATING CAPACITY TEST continued



AH unit no.__________ Date________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 10 | Test for steady state at 5 minute intervals: (max diff 2 F) average lvg air temp: _____, _____, _____ F | | | | 10 |
| 11 | Measure barometric pressure _____ in.Hg | | | | 11 |
| 12 | Measure and record 3 sets of test data at 5 min intervals: (1, 2, 3) Ent air temp _____, _____, _____ F; Lvg air temp _____, _____, _____ F | | | | 12 |
| 13 | Calculate heating capacity: | | | | 13 |
| 13a | Saturated water vapor, Psw: | | | | 13a |

$$P_{sw} = e^{[15.4638 - 7284/(Td+392)]}$$

$$(P_{sw})_{ent} = e^{[15.4638 - 7284/(\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

13b Vapor pressure, $P_w$: 13b

$$P_w = RH \times P_{sw}$$

$$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

COMMENTS: ______________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HEATING CAPACITY TEST continued
Page 12

AH unit no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

13c Humidity ratio, W: 13c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$$(W)_{ent} = 0.622 \times \frac{\_\_\_\_}{\_\_\_\_ - \_\_\_\_} = \_\_\_\_ \text{ lb vapor/lb dry air}$$

$$(W)_{lvg} = (W)_{ent} = \_\_\_\_ \text{ lb vapor/lb dry air}$$

13d Enthalpy, H: 13d

$$H = 0.24 \times Td + W\ (1061 + 0.444 \times Td)$$

$$(H)_{ent} = 0.24 \times \_\_\_\_ + \_\_\_\_\ (1061 + 0.444 \times \_\_\_\_) = \_\_\_\_ \text{ Btu/lb}$$

$$(H)_{lvg} = 0.24 \times \_\_\_\_ + \_\_\_\_\ (1061 + 0.444 \times \_\_\_\_) = \_\_\_\_ \text{ Btu/lb}$$

13e Specific volume of air, v: 13e

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b}\ (1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_ + 460)}{P_b}\ (1 + 1.6078 \times W) = \_\_\_\_ \text{ cu ft/lb}$$

COMMENTS:________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HEATING CAPACITY TEST continued



AH unit no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 13f | Mass flow rate of air, M: | | | | 13f |

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_\_} = \_\_\_\_\_ \text{ lb/min}$$

| | | | | | |
|---|---|---|---|---|---|
| 13g | Coil heating capacity, C: | | | | 13g |

$$C = 60 \text{ M x } [(H)_{lvg} - (H)_{ent}]$$

$$= 60 \text{ x } \_\_\_\_\_ \text{ x } (\_\_\_\_\_ - \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/h}$$

| | | | | | |
|---|---|---|---|---|---|
| 13h | Repeat calculations for all 3 sets of data, Averaged heating capacity: | | | | 13h |

(_____ + _____ + _____)/3 = _____ Btu/h

| | | | | | |
|---|---|---|---|---|---|
| 14 | Acceptance criteria: | | | | 14 |

C > 0.95 x * capacity > 0.95 x _____ > _____

COMMENTS:________________________________________

__________________________________________________

__________________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, COOLING CAPACITY TEST continued
Page 14

AH unit no.____________

Date__________
Inspection agent________________

Commissioning team______________
______________
______________

Notes for using form:
1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | For air cooled condensing system, measure outside air temp; if it differs more than 2 F from specified, postpone test (*_____ F) _____ F | | | | 1 |
| 2 | For water cooled condensing system, measure and adjust condensing w temp to within 2 F from specified (*_____ F) _____ F; measure and adjust cond w flow rate to within 3% of specified (*_____gpm) _____gpm | | | | 2 |
| 3 | Air flow rate (from air flow rate test, WS-2, page2) _____ cfm | | | | 3 |
| 4 | Measure entering air temp & humidity; apply false load if needed (*_____ F, *_____ % RH) average temp _____ F, _____ % RH | | | | 4 |
| 5 | Make sure cooling is on during test | | | | 5 |
| 6 | Run unit for at least 20 minutes | | | | 6 |
| 7 | Measure barometric pressure _____ in.Hg | | | | 7 |

COMMENTS:________________________________________________
________________________________________________
________________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, COOLING CAPACITY TEST continued


AH unit no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | Measure and record 3 sets of test data at 10 min intervals: | | | | 8 |

1 2 3

Ent air temp _____,_____,_____ F
Lvg air temp _____,_____,_____ F
Ent air humidity _____,_____,_____ %
Lvg air humidity _____,_____,_____ %

9 Calculate cooling capacity: 9
9a Saturated water vapor of air, Psw: 9a

$P_{sw} = e^{[15.4638 - 7284/(Td+392)]}$

$(P_{sw})_{ent} = e^{[15.4638 - 7284/(\_\_\_\_\_ + 392)]}$ = _____ in. Hg

$(P_{sw})_{ent} = e^{[15.4638 - 7284/(\_\_\_\_\_ + 392)]}$ = _____ in. Hg

9b Vapor pressure, Pw: 9b

$P_w = RH \times P_{sw}$

$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times$ _____ = _____ in.Hg

$(P_w)_{lvg} = 0.5 \times (P_{sw})_{lvg} = 0.5 \times$ _____ = _____ in.Hg

COMMENTS:______________________________________________
______________________________________________
______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, COOLING CAPACITY TEST continued
Page 16

AH no.________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

9c Humidity ratio, W: 9c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$$(W)_{ent} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} = \_\_\_\_\_ \text{ lb vapor/lb dry air}$$

$$(W)_{lvg} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} = \_\_\_\_\_ \text{ lb vapor/lb dry air}$$

9d Enthalpy, H: 9d

$$H = 0.24 \times Td + W\,(1061 + 0.444 \times Td)$$

$$(H)_{ent} = 0.24 \times \_\_\_\_\_ + \_\_\_\_\_\ (1061 + 0.444 \times \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/lb}$$

$$(H)_{lvg} = 0.24 \times \_\_\_\_\_ + \_\_\_\_\_\ (1061 + 0.444 \times \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/lb}$$

9e Specific volume of air, v: 9e

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b}\ (1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_\_ + 460)}{P_b}\ (1 + 1.6078 \times W) = \_\_\_\_\_ \text{ cu ft/lb}$$

COMMENTS:______________________________________________

______________________________________________

______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, COOLING CAPACITY TEST continued


AH no.__________________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 9f | Mass flow rate of air, M: | | | | 9f |

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_\_} = \_\_\_\_\_ \text{ lb/min}$$

9g Coil cooling capacity, C: 9g

$$C = 60\ M \times [(H)_{lvg} - (H)_{ent}]$$

$$= 60 \times \_\_\_\_\_ \times (\_\_\_\_\_ - \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/hr}$$

9h Repeat calculations for all 3 sets of data, Averaged heating capacity: 9h

(_____ + _____ + _____)/3 = _____ Btu/h

10 Acceptance criteria: 10

C > 0.95 x * capacity > 0.95 x _____ > _____

COMMENTS:_______________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HUMIDIFIER CAPACITY TEST continued
Page 18

AH unit no.________
Type _______________

Date__________
Inspection agent_________________

Commissioning team________________
________________
________________

Notes for using form:

1. Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.
2. "*" and subscript "s" denote data required from specification, drawings, manufacturer's manuals or by calculations. Copy in blanks.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Air flow rate (from air flow rate test, WS-2, page 2) _____ cfm | | | | 1 |
| 2 | Measure entering air temp & humidity _____ F, _____ % RH | | | | 2 |
| 3 | Estimate leaving air humidity; leaving air should not damage building and equipment; otherwise postpone test | | | | 3 |
| 4 | Measure & adjust steam temp & pressure to within 1 psi of specified (for unit with steam humidifier only) (*_____ psi) _____ psi _____ F Is steam saturated? | | | | 4 |
| 5 | Set humidifier control to full capacity | | | | 5 |
| 6 | Run system for at least 10 minutes | | | | 6 |
| 7 | Take 3 sets of test data at 5 min intervals: | | | | 7 |

| | 1 | 2 | 3 | |
|---|---|---|---|---|
| Ent air temp | _____ | _____ | _____ | F |
| Lvg air temp | _____ | _____ | _____ | F |
| Ent air humidity | _____ | _____ | _____ | % RH |
| Lvg air humidity | _____ | _____ | _____ | % RH |

COMMENTS:____________________________________________________________
______________________________________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HUMIDIFIER CAPACITY TEST continued Page 19

AH unit no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 8 | Calculate humidifier capacity: | | | | 8 |
| 8a | Saturated water vapor of air, Psw: | | | | 8a |

$$P_{sw} = e^{[15.4638 - 7284/(Td+392)]}$$

$$(P_{sw})_{ent} = e^{[15.4638 - 7284/(\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

$$(P_{sw})_{ent} = e^{[15.4638 - 7284/(\_\_\_\_\_ + 392)]} = \_\_\_\_\_ \text{ in. Hg}$$

8b Vapor pressure, $P_w$: 8b

$$P_w = RH \times P_{sw}$$

$$(P_w)_{ent} = 0.5 \times (P_{sw})_{ent} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

$$(P_w)_{lvg} = 0.5 \times (P_{sw})_{lvg} = 0.5 \times \_\_\_\_\_ = \_\_\_\_\_ \text{ in.Hg}$$

8c Humidity ratio, W: 8c

$$W = 0.622 \times \frac{P_w}{P_b - P_w}$$

$$(W)_{ent} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} = \_\_\_\_\_ \text{ lb vapor/lb dry air}$$

$$(W)_{lvg} = 0.622 \times \frac{\_\_\_\_\_}{\_\_\_\_\_ - \_\_\_\_\_} = \_\_\_\_\_ \text{ lb vapor/lb dry air}$$

COMMENTS:________________________________________

TEST WORK SHEET WS 8B-2 -- UNITARY ROOFTOP AND COMPUTER ROOM UNIT, HUMIDIFIER CAPACITY TEST continued
Page 20

AH unit no.____________ Date__________

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|

8d Specific volume of air, v: 8d

Note: Measurement location of Td and flow rate must be consistent.

$$v = \frac{0.754 \times (Td + 460)}{P_b} (1 + 1.6078 \times W)$$

$$= \frac{0.754 \times (\_\_\_\_\_ + 460)}{P_b} (1 + 1.6078 \times W) = \_\_\_\_\_ \text{ cu ft/lb}$$

8e Mass flow rate of air, M: 8e

$$M = \frac{cfm}{v} = \frac{cfm}{\_\_\_\_\_} = \_\_\_\_\_ \text{ lb/min}$$

8f Humidifier capacity, C: 8f

$$C = 60\ M \times [(W)_{lvg} - (W)_{ent}]$$

$$= 60 \times \_\_\_\_\_ \times (\_\_\_\_\_ - \_\_\_\_\_) = \_\_\_\_\_ \text{ Btu/hr}$$

8g Repeat calculations for all 3 sets of data,
Averaged heating capacity: 8g

$$(\_\_\_\_\_ + \_\_\_\_\_ + \_\_\_\_\_)/3 = \_\_\_\_\_ \text{ Btu/h}$$

9 Acceptance criteria: 9

C > 0.95 x * capacity > 0.95 x _____ > _____
Humidifier does not "spit"

COMMENTS:________________________________________

## 8.6 TEST WORK SHEET WS 8B-3 -- UNITARY PTAC TEST

AH unit no.________________ Date__________
Room no.____________________ Inspection agent_________________

Make & model________________ Commissioning team_______________
Heating type: Hot water____
(check one) Electric_____

Note for using form:
Follow the steps outlined in the form and place check marks or fill data as required. Initial under "pass" or "fail" colums, supply remarks if necessary.

| No. | Steps | Check mark | Pass | Fail & Remarks | No. |
|---|---|---|---|---|---|
| 1 | Verify ARI certification symbol (if specified) | | | | 1 |
| 2 | Turn unit control to on, verify fan operation | | | | 2 |
| 3 | Turn ventilation control to off | | | | 3 |
| 4 | Turn cooling control to on, make sure thermostat setting is at least 10 F below room temperature | | | | 4 |
| 5 | Measure discharge air temperature, discharge air is below 60 F | | | | 5 |
| 6 | Turn heating control to on, make sure thermostat setting is at least 10 F below room temperature | | | | 6 |
| 7 | If system is hot water, make sure hot water temperature is as specified | | | | 7 |
| 8 | Measure discharge air temperature, discharge air is above 120 F | | | | 8 |
| 9 | Turn ventilation control to on | | | | 9 |
| 10 | Verify ventilation air damper is open | | | | 10 |

COMMENTS:______________________________________________

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

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James Y. Kao

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10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

This guide is developed for the Public Building Service (PBS) of the General Services Administration (GSA) for final inspection and testing of heating, ventilating, and air-conditioning (HVAC) systems in Federal buildings prior to Government acceptance. The guide describes in detail the functional inspection and testing procedures and calculations. It includes eight chapters: General, Instrumentation and Basic Measurement, Refrigeration Plant, Heating Plant, Air Handling Equipment and systems, Building Automation Systems, Fire Safety Air Moving Systems, and Unitary Air Handling Equipment. The appendix contains detailed inspection checklist and test work sheets designed to be used in the field.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

air handling system test; building automation system test; commissioning; field test; fire safety test; functional test; heating plant test; inspection; smoke control test; refrigeration plant test

13. AVAILABILITY

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