

## Appendix

<b>Glossary of Terms for HVAC Controls</b>	A-1
<b>Example SoO for single-zone package rooftop unit</b>	B-1
<b>Example Functional Test Procedure for single-zone package rooftop unit</b>	C-1
<b>Activity 3 Answer Sheet - SoO for single zone constant volume air system with economizer</b>	D-1
<b>Activity 4 Answer Sheet - Function Test Procedure for single zone constant volume air system with economizer</b>	E-1
<b>Example BAS Screen Check Answer Sheet</b>	F-1

*A lasting resource for the future*



## Glossary

<b>Analog</b>	A continuously variable number. Analog refers to a representation of a quantity that varies over any continuous range of values.
<b>Artificial Intelligence</b>	When computers think and make decisions (related to machine learning).
<b>BACnet</b>	Communications protocol designed by ASHRAE to connect building components.
<b>Chiller</b>	Electrical, steam or waste heat powered device that cools down water or other fluid.
<b>Commissioning</b>	A process that verifies all systems are operating and integrated as intended.
<b>Condensate</b>	Liquid water condensed from vapor.
<b>Control Response</b>	Controller’s programmed response to input about the controlled variable <ul style="list-style-type: none"><li>• 2 position: Either turn controlled device on or off based on whether controlled variable is above setpoint or not.</li><li>• Floating: Controller response to sensor input varies depending on how far controlled variable is from setpoint.</li></ul>
<b>Control Agent</b>	In a control system, the medium manipulated by the controlled device. <u>Examples</u> : air or gas flowing through a damper; gas steam or water flowing through a valve; or an electric current.
<b>Control Drawings</b>	Original, verified, as-built plans, including updates for changes.
<b>Control Loops</b>	There are two basic types of control loops, open and closed. Closed is also known as “feedback control.” Closed-loop control is where the controlled variable, such as space temperature, feeds data back to the controller. Open loop control lacks any feedback mechanism.

<b>Control Point</b>	The actual value of a measured variable (or controlled variable) at any given moment.
<b>Controlled Device</b>	Reacts to the signal received from a controller and varies the flow of the control agent. It may be a valve, damper, electric relay or a motor driving a pump or a fan. Examples: control valves, damper actuators, variable speed drives.
<b>Control Valves</b>	Devices that can be constricted to control liquid flow. Three common varieties are:  2-way: one inlet, one outlet 3-way mixing: 2 inlets, one outlet 3-way diverting: 1 inlet, 2 outlets
<b>Controlled Variable</b>	In a control system, the condition being controlled. Examples: temperature, humidity, or pressure.
<b>Controller</b>	In a control system, the controller compares the value of the variable with the setpoint or desired value, and outputs a signal based on the difference between the variable and the set point. Examples: thermostats, humidistats, and pressure controllers.
<b>Cooling Tower</b>	An energy efficient device that sprays and recollects water to cool the water in a cooling loop. Air circulating through the cooling tower absorbs the excess heat. Cooling towers can use a lot of water.
<b>Dampers</b>	Shutters that control flow of air or gases.
<b>DDC</b>	Direct Digital Control, using intelligent stand-alone microprocessor controllers. DDC control consists of microprocessor-based controllers with the control logic performed by software. Analog-to-Digital (A/D) converters transform analog values into digital signals that a microprocessor can use, then converted back to analog or binary (digital) form to control physical devices.
<b>Deadband</b>	The temperature range in which no heating or cooling is used. Deadband thermostats have a wide differential over which the thermostat remains neutral and neither heating or cooling is required. This differential is often adjustable.

<b>Demand Response</b>	The Utility sends a signal to the BAS that electricity will be expensive, so BAS should turn down HVAC or other loads to avoid peak demand charges.
<b>Differential</b>	Value used in 2 position response that sets the range in which controlled device is enabled.
<b>Digital</b>	Communication using 1's (on) and 0's (off), bits, as in computers.
<b>Direct Digital Controls</b>	Control system uses digitized data with logic to derive how controlled devices should be set.
<b>Dual Duct HVAC System</b>	Hot and cold ducts from air handler are blended in mixing box to serve multiple zones.
<b>Air-Side Economizer</b>	Blowing cool outdoor air into building during shoulder seasons in place of running chiller.
<b>Water-Side Economizer</b>	Relying exclusively on the cooling tower to provide cold water in the water loop. It bypasses the chiller because the outside air temperature is cold enough.
<b>Electric Control System</b>	An electrically controlled system that uses low line voltage (24 Vac) electrically controls the controlled device.
<b>Enthalpy</b>	Total heat content of air including both sensible (dry bulb) and latent (humidity). Units: BTU/lb or J/g.
<b>Humidistat</b>	An automatic control device that measures humidity, and is used to maintain humidity at a fixed or adjustable set point.
<b>Interchangeability</b>	Ability to use different components together. Often the result of an open standard.
<b>Interoperability</b>	The ability of computer hardware and software, even that made by different manufacturers, to work together.
<b>LonTalk</b>	Echelon's proprietary network protocol.
<b>LonWork</b>	Network of building components that communicate using LonTalk.
<b>Machine Learning</b>	Computers analyze past data to develop future operational practices.

<b>Microprocessor</b>	The chip that “thinks” in a computer.
<b>Modbus</b>	A serial communications protocol common in industrial environments.
<b>Multizone HVAC System</b>	One air handler blows air to multiple zones. Zone thermostats control dampers in zone.
<b>Optimal Start/Stop</b>	BAS system automatically determines when HVAC needs to start in the morning and stop in the evening based on the outdoor temperature and configured occupancy schedule to meet required conditions.
<b>Overshoot</b>	How much over setpoint controlled variable rises.
<b>Open source system</b>	Control software code is available to the general public.
<b>Plenum</b>	The region above the ceiling tiles where return air is typically collected.
<b>Pneumatic Controls</b>	Communication using pressurized air in tubes or pneumatic lines.
<b>Points</b>	Real or virtual locations where connections occur between equipment. Includes input from sensors and output signals to controlled devices.
<b>Point types</b>	<ul style="list-style-type: none"><li>• AI/UI: Analog/Universal Input. Examples: temperature, pressure, flow</li><li>• AO: Analog Output. Examples: damper motor, control valve</li><li>• BI/DI: Binary/Digital Input</li><li>• BO/DO: Binary/Digital Output</li></ul>
<b>Process Plant</b>	Equipment being controlled. Examples: Coils, ducts, fans.
<b>Proportional Control</b>	The controlled device setting depends proportionally on sensor position.
<b>Proportional-Integral</b>	A control algorithm or method that combines the proportional and integral control algorithms. By measuring how quickly the system reacts, PI tends to eliminate the offsets inherent in Proportional control.

**Proportional-Integral-Derivative (PID)**

A control algorithm or method that enhances the PI control by adding a component that is proportional to the rate of change (derivative) of the deviation of the controlled variable. This method compensates for system changes and allows faster control response.

**Primary Air**

Air which is mixed, during combustion, with the fuel just before the point of combustion.

**Process Plant**

In a control system, the apparatus being controlled. It reacts to the output of the control agent and affects the change in the controlled variable. It may include a coil, air duct, fan or occupied space of the building.

**Proportional Control**

A control algorithm or method in which the final control element moves to a position that is proportional to the amount that the controlled variable is away from the setpoint.

**Proprietary Systems**

The computer programming code is not available to the public.

**Pulse-width Modulation**

Method of inverting and chopping sine wave to achieve frequency control in adjustable speed drives.

**Reset**

Turning down boilers and chillers from their design day temperatures to lower energy settings based on schedules or lower load requirements.

**Resistive Temperature Device**

A thermal sensor based on electrical resistance that responds linearly, usually with a positive temperature coefficient.

**Sensor**

In a control system, the device that measures a variable and transmits its value to the controller.

**Set point**

The desired condition for the controller.

**Single Zone HVAC system**

One thermostat controls HVAC system for a limited space.

**Smart Building**

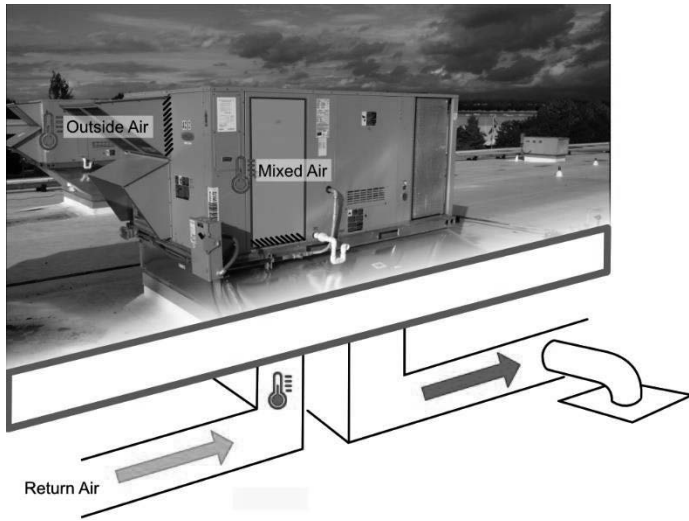
A building that utilizes modern technologies to self-diagnose faults, identify its most efficient operations to keep occupants comfortable, and communicate with the utility to optimally utilize energy sources like renewable energy.

<b>Software</b>	Computer programs
<b>Sub-Metering</b>	Owner installed meters that track building energy usage and can help identify inefficiencies.
<b>Thermistor</b>	A thermal sensor that often has non-linear response.
<b>Thermostat</b>	Combination of temperature sensor and controller.
<b>Throttling VAV terminal units</b>	VAV box that controls the amount of primary air flowing into the terminal unit to control the temperature.
<b>Trend data</b>	A time series graph of any variable.
<b>Two Position</b>	Control action in which the controlled device can be positioned only in a maximum or minimum state, or can either be on or off.
<b>VAV</b>	Variable Air Volume. Air flow is varied to match heating and cooling loads.
<b>Ventilation Air</b>	Fresh, outdoor air is required to lower CO2 levels. It should be kept to a minimum since it requires a lot of energy to condition.
<b>VFD</b>	Variable Frequency Drive (also VSD, Variable Speed Drive or ASD, Adjustable Speed Drive). Variable frequency drive systems provide adjustable speed operation of motors that drive, for example, fans, blowers, compressors, and pumps for HVAC equipment, and other types of loads. VFD systems take an alternating current with a fixed voltage and frequency, and change it into an alternating current with adjustable voltage and frequency. Motor speed can then be adjusted and coordinated to match exact process flow requirements.

## APPENDIX

### Example Sequence of Operation (SoO): Single Zone Package Rooftop Unit

*Disclaimer: This example SoO is intended for instructional purposes. It is not written or recommended for application in a real world setting.*



Here is a single-zone constant volume package rooftop AC unit with gas heating, compressor cooling, economizer cooling and a single supply fan. The economizer has integral barometric relief. Temperature and scheduling control is by a programmable thermostat with optimum start capability.

#### **Operating Schedule and Setpoints**

Occupied mode:	Monday thru Friday 7am to 6pm
Unoccupied mode:	Weekday evenings, Saturday & Sunday
Occupied heating setpoint	70°F.
Occupied cooling setpoint	75°F.
Unoccupied heating setpoint	55°F.
Unoccupied cooling setpoint	85°F.
Economizer control type	Integrated economizer with fixed dry bulb temperature setpoint
Economizer changeover temperature	70°F

#### **SEQUENCE OF OPERATION**

**Occupied Mode:** Supply fan is on and runs continuous. Outside air damper is open to minimum position for ventilation. On a drop in space temperature below the heating setpoint of 70°F (adj.) the gas furnace cycles as required to maintain heating setpoint temperature. On a rise in temperature above the cooling setpoint of 75°F (adj.) cooling is enabled. If the outside air temperature is below the economizer changeover setpoint temperature of 75°F, the economizer shall be the first stage of cooling and shall cycle as required to maintain cooling setpoint temperature. If economizer cooling is unable to maintain the cooling setpoint the AC compressor(s) shall cycle as required to maintain setpoint. If the outside air temperature is above the economizer changeover temperature the economizer damper shall close to minimum position for ventilation.

**Unoccupied Mode:** The supply fan is off and the outside air damper is closed. On a drop in space temperature below the unoccupied heating setpoint temperature of 55°F(adj.) the supply fan and gas furnace shall cycle as required to maintain the unoccupied temperature setpoint. The outside air damper shall remain closed. On a rise in temperature above the unoccupied temperature setpoint of 85°F (adj.) the cooling shall be enabled. The supply fan, economizer and AC compressor shall cycle as required to maintain the unoccupied temperature setpoint. The outside air damper shall remain closed.

**Warmup Mode:** System start time shall be determined by the programable thermostat. During the building warmup period, the supply fan shall run continuous. The outside air damper shall be closed. The gas furnace shall operate as required to meet the occupied temperature setpoint of 70°F. (adj.). When the space temperature setpoint is met the system shall change to the occupied mode of operation.

# APPENDIX

## Example Functional Test Procedure: Single Zone Package Rooftop Unit

Equipment ID: \_\_\_\_\_ Date of Testing \_\_\_\_\_

Person(s) Performing Testing \_\_\_\_\_

Outside air temperature at time of testing \_\_\_\_\_

### OCCUPIED MODE

1. Verify setpoints and schedules match sequence of operation.....Yes No  
If no, how do the settings deviate from the SoO?

\_\_\_\_\_  
\_\_\_\_\_

2. Set thermostat to occupied mode heating. Does the fan run continuously?.....Yes No  
Is the outside air damper open to minimum position? .....Yes No

Notes: \_\_\_\_\_

3. In the occupied mode, set heating setpoint to 5°F. higher than room temperature.  
Is the heating enabled? .....Yes No

Record supply air temperature \_\_\_\_\_

Notes: \_\_\_\_\_

4. In the occupied mode, set the cooling setpoint to 5°F cooler that the space temperature.  
Is cooling enabled?.....Yes No  
If the outside air temperature is less than the economizer setpoint is economizer enabled? .. Yes No  
If the outside air temperature is greater that the econo. setpoint is economizer disabled?..... Yes No  
Record supply air Temperature \_\_\_\_\_

### UNOCCUPIED MODE

1. Set thermostat to unoccupied mode.  
Is the outside air damper 100% closed? ..... Yes No  
Is the supply fan off? ..... Yes No

Notes: \_\_\_\_\_

2. Set unoccupied heating setpoint to 5°F warmer than the space temperature.  
Is the heating enabled?..... Yes No  
Is the outside air damper 100% closed ..... Yes No

Notes: \_\_\_\_\_

3. Set unoccupied cooling setpoint to 5°F cooler than the space temperature.  
Is the cooling enabled? ..... Yes No  
If the outside air temperature is less than the economizer setpoint is economizer enabled? .. Yes No  
If the outside air temperature is greater that the econo. setpoint is the damper closed? ..... Yes No

Notes: \_\_\_\_\_



## **APPENDIX**

### **Activity 3 Answer Sheet – SoO for single zone constant volume air system with economizer**

#### **OCCUPIED MODE (MONDAY-SATURDAY 9AM-10PM)**

1. Supply fan is on and runs continuous at a constant speed
2. Outside air damper is open to minimum position. Return air damper is open. Exhaust damper is closed
3. On a call for heating, heating is enabled and the hot water valve modulates open to maintain discharge air temperature setpoint
4. Economizer cooling: The first stage of cooling shall be economizer if the outside air temperature is less than the economizer changeover setpoint temperature. In economizer cooling mode the return air damper and the outside air damper shall modulate to maintain minimum discharge air temperature setpoint. The exhaust damper shall open for relief.
5. Economizer Cooling & Chilled Water Cooling: If the economizer is unable to maintain the cooling setpoint the chilled water cooling shall be enabled. The chilled water valve shall open and modulate to maintain the discharge air temperature setpoint of 55F.
6. Chilled Water Cooling Only: If the outside air temperature is above the economizer changeover temperature the outside air damper shall be at minimum position. The return air damper is open and the exhaust air damper is closed. Cooling is enabled and the chilled water valve shall modulate open to maintain discharge air temperature setpoint.

#### **UNOCCUPIED MODE (SUNDAYS)**

1. Supply fan is off. Outside air damper is close. Exhaust air damper is closed. Outside air damper is open.
2. On a call for heating, the supply fan is on and runs continuous at a constant speed. The outside air damper is closed. The return air damper is open. The hot water valve modulates to maintain discharge air temperature setpoint.
3. On a call for cooling, the supply fan is on and runs continuous at constant speed. The outside air damper is closed. The return air damper is open. The hot water valve modulates to maintain discharge air temperature setpoint.

###

# APPENDIX

## Activity 4 Answer Sheet – Functional Test Procedure for single zone constant volume air system with economizer

### OCCUPIED MODE

Place unit in the occupied mode of operation

1. Supply fan is on and runs continuous ..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

2a. Outside air damper is open to minimum position ..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

2b. Return air damper is open ..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

2c. Relief/exhaust air damper is closed?  
In the occupied mode, set heating set ..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

3a. Set heating setpoint to 5F above zone temperature. Is heating enabled? ..... Yes No

3b. Does hot water valve modulate open to maintain discharge air temperature setpoint?..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

4a. When outside air temperature is less than economizer changeover setpoint temperature set cooling setpoint to 5F below zone temperature. Is cooling enabled? ..... Yes No

4b. Is economizer cooling enabled?..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

5. Can economizer cooling and chilled water cooling be enabled at the same time? ..... Yes No  
If no, how do the settings deviate from the SoO?

---

---

6a. When outside air temperature is greater than economizer changeover temperature set the cooling setpoint to 5F below zone temperature. Is economizer enabled..... Yes No

If no, how do the settings deviate from the SoO?

---

---

6b. Is chilled water cooling enabled?..... Yes No?

If no, how do the settings deviate from the SoO?

---

---

## UNOCCUPIED MODE

Place unit in the unoccupied mode

1a. Supply fan is off..... Yes No

If no, how do the settings deviate from the SoO?

---

---

1b. Outside air damper is closed..... Yes No

If no, how do the settings deviate from the SoO?

---

---

1c. Relief/exhaust damper is closed ..... Yes No

If no, how do the settings deviate from the SoO?

---

---

2a. Set heating setpoint to 5F above zone temperature. Is supply fan on? ..... Yes No

Does hot water valve modulate to maintain heating discharge temperature? ..... Yes No

If no, how do the settings deviate from the SoO?

---

---

2b. Outside air damper is closed..... Yes No

If no, how do the settings deviate from the SoO?

---

---

2c. Relief/exhaust damper is closed ..... Yes No

If no, how do the settings deviate from the SoO?

---

---

3a. Set cooling setpoint to 5F below zone temperature. Is supply fan on? ..... Yes No

Is economizer or chilled water cooling enabled? ..... Yes NO

If no, how do the settings deviate from the SoO?

---

---

3c. Economizer and/or mechanical cooling valve modulate to maintain cooling discharge temp... Yes No  
If no, how do the settings deviate from the SoO?

---

---

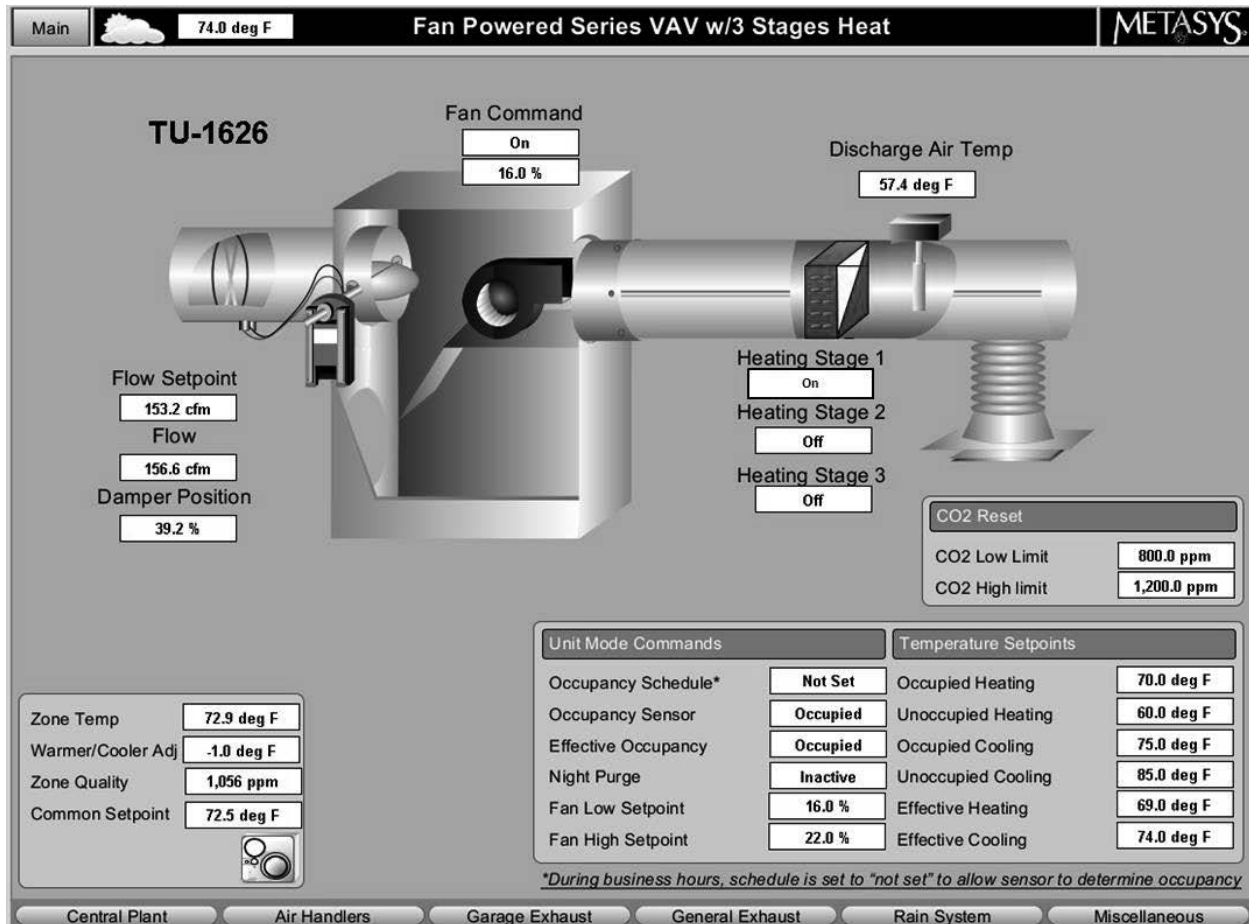
## **LIST MAINTENANCE TASKS**

1. Verify critical sensor accuracy (outside air temperature and discharge air temperature)
2. Lubricate damper linkage and damper pivot points
3. Adjust dampers to ensure tight closure
4. Verify accuracy of zone thermostat temperature
5. Verify thermostat schedules match occupancy
6. Clean heat exchangers
7. Change filters
8. Check controller electrical connections and tighten as required
9. Lubricate fan bearings and adjust fan belt tension (as required)
10. Functionally test SoO annually

###

# APPENDIX

## Class Discussion Answer Sheet: Example BAS Screen Check



Answers to example BAS screen check:

- Given a sequence of operation that states that fan speed should vary linearly between 16 percent (minimum) and 22 percent (maximum) corresponding to CO<sub>2</sub> levels between 800 ppm and 1200 ppm, respectively, what would you expect the fan speed to be at the current operating condition (approximately)?

*Answer: Zone quality is 1,056 ppm. If fan speed is supposed to vary linearly between 16 percent (at 800 ppm) and 22 percent (at 1200 ppm), performing linear interpolation, the fan speed should be operating at or near 20%.*

- Do you see any other potential operational problems with TU-1626?

*Answer: One of the heating stages is "indicated" on when it shouldn't be. This is indicated by the zone temperature being greater than the setpoint.*

*Stage 1 heating is indicated "on" yet no heating is occurring. This is indicated by the discharge air temperature reading*

*Fan speed typically follows primary air damper position yet the setpoint indicates a maximum of 22% fan speed. Operator needs to verify SoO.*