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**Multizone to Variable Volume HVAC Controls Retrofit Design Guide**

October 2022

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Prepared under Environmental Security Technology Certification Program   
Energy and Water Projects EW-195026

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# INTRODUCTION

This Design Guide serves as an overall roadmap to support implementation of a variable volume retrofit of a multizone (MZ) HVAC system for increased energy efficiency. Activities range from selecting which air handling unit(s) (AHUs) are good candidates for retrofit, through preparing contract documents for award, to performing inspections and tests leading to system acceptance/turnover. This document includes technical requirements along with a process for implementation that make use of supporting tools (e.g., documents, procedures, spreadsheets and drawings) developed in conjunction with this guide[[1]](#footnote-1).

Sections 4 and 5 together are approximately 7 pages long and provide the most important information in this guide: the retrofit process, key implementation considerations, and assembly of a contract package. Most of the rest of this Design Guide is either introductory or reference material.

This Design Guide is assembled as follows:

* Section 1, 2 and 3 – introduction to the retrofit and multizone units
* Section 4 and 5 – process of implementing the retrofit – *KEY INFORMATION*
* Section 6 – detailed technical requirements for reference
* Appendix A through G – templates for a Performance Work Statement (including sample Performance Verification Test), Specification Book, and Controls Sequences of Operation as well as references for implementing the retrofit.

# RETROFIT TECHNICAL OVERVIEW

This Design Guide describes a technique to convert an existing constant volume multizone system to a variable volume (MZ-VV) multizone system. The technique makes limited changes in instrumentation and equipment control schemes. This is a significantly less disruptive and less costly approach than the common full system change-out (to Variable Air Volume (VAV)), that would require demolition and replacement of the central air handling unit along with installation of new ductwork and terminal units for the spaces.

Figure 1 illustrates the basic retrofit. The retrofit technique includes installing a variable frequency drive(s) (VFD(s)) on the air handling unit (AHU) supply (and return) fan motor(s), installing an outside airflow measurement array (AFMA) in the outside air duct, and modifying controls programming.

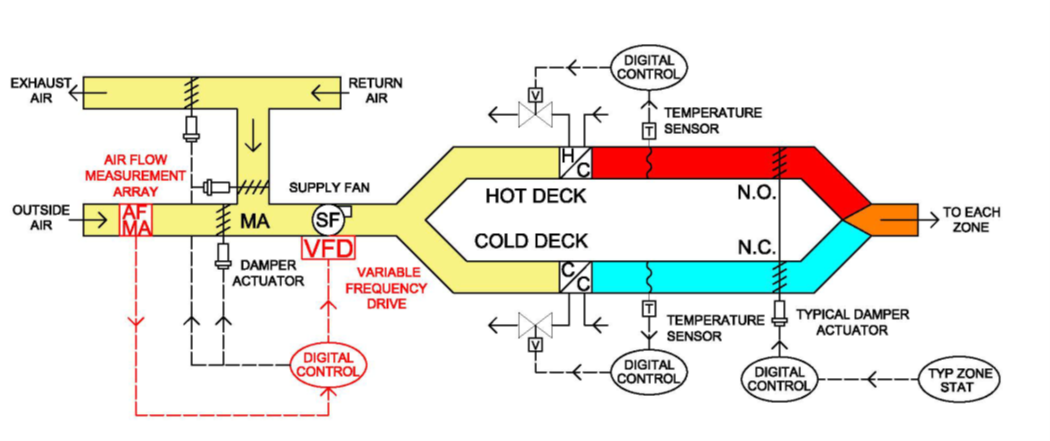


Figure 1. Multizone with Variable Volume Control (red fonts highlight the retrofit components).

The retrofit technique avoids or minimizes the inefficiency of the constant volume airflow typical of all multizone designs, and, where applicable, the simultaneous heating and cooling inherent in conventional MZ systems. Energy waste is reduced through control logic that 1) employs a variable speed fan to turn down airflow while still meeting space conditioning and ventilation needs, 2) closes the hot and cold coil water valves when not needed, and 3) resets the hot deck temperature to maximize energy cost savings.

The VFD allows for fan capacity control. This ability to operate the fan at reduced speed provides electrical energy savings. Fan operation is automatically adjusted based on the position of the (multiple) zone dampers where fan speed is decreased until one of the zone dampers is at full or near full open position. The objective is to let the dampers open wide so that the fan speed can be lower while still getting adequate heat transfer to provide the needed conditioning to the zone.

The AFMA provides measurement of outside airflow to the control scheme that modulates the outside air (mixed air) damper(s) to maintain proper ventilation and/or makeup airflow, especially as the VFD varies the total system airflow.

The valve control modification provides thermal savings in the coils that impacts site utility bills in the form of energy savings of the heating or cooling equipment (e.g., natural gas of a boiler or electric energy used for a chiller).

The binary hot deck temperature reset modulates deck temperature to a high or low set point depending on weather. At the warmer setpoint (during colder weather), a ‘hotter’ deck air temperature allows a lower airflow rate to meet zone heating load. The resulting fan energy savings is typically more beneficial than thermal savings because of the greater cost of electricity versus natural gas. At the cooler setpoint, (during warmer weather) excess heating in the coil (and excess standby loss) is reduced as coil capacity better matches warm weather needs.

An optional demand controlled ventilation (DCV) control scheme uses sensors in the space to detect periods of no or low occupancy and achieves further energy savings through reduction of outdoor air ventilation when spaces are not used.

In addition to the VFD and AMFA of the basic retrofit, there may be other site specific equipment needed to support desired control of the system. The retrofit will need direct digital control (DDC) and is expected to be done at the same time as a DDC upgrade. Depending on the state of repair of the existing system, the retrofit may require replacement of controllers, actuators and/or sensors to provide for accurate monitoring and control of the system. The retrofit might require the replacement of the fan motor(s) with a VFD-compatible motor. Replacement of an older motor can provide for additional energy savings if the new motor is a higher efficiency motor. The demand controlled ventilation option will require addition of CO2 or occupancy sensors in the space.

The ideal retrofit candidate is a conventional multizone where the hot and cold decks are operated simultaneously, and the unit is scheduled for a DDC upgrade. Other types are suitable, but the Return on Investment (ROI) will likely not be as good.

This Design Guide is based on a field demonstration project performed by the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) under the DoD Environmental Security Technology Certification Program (ESTCP). A suite of implementation support tools has been developed to facilitate adoption of the retrofit. See Figure 2. These implementation resources help a potential user through the entire process of evaluating, procuring, and using the technology. See Figure 3. The suite includes this Design Guide (with template Performance Work Statement, template Specification Book, and template Sequences of Operation in the appendix), template Control Drawings, template Points Schedules, a Technical Note, an ESTCP Fact Sheet, a Field Scoping Guide, a Savings Estimator Tool, a Pitch Briefing Slide, and Commissioning Guidance (with Performance Verification Test). These resources are posted on the Whole Building Design Guide at [www.wbdg.org/ffc/army-coe/design-guides](http://www.wbdg.org/ffc/army-coe/design-guides)/mz-vv-hvac-controls-retrofit. Free on-demand training on the technology is available at: https://www.wbdg.org/continuing-education/dod-courses/estcp/estcp4-4.

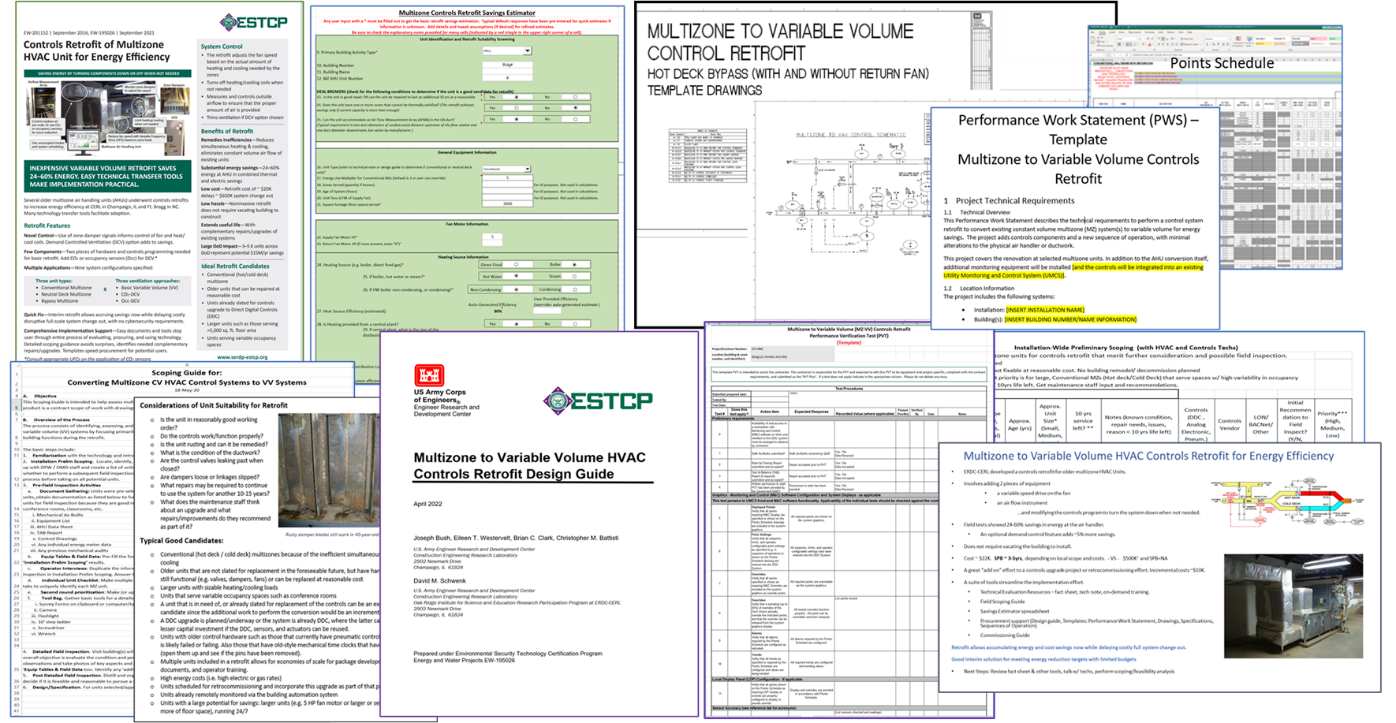
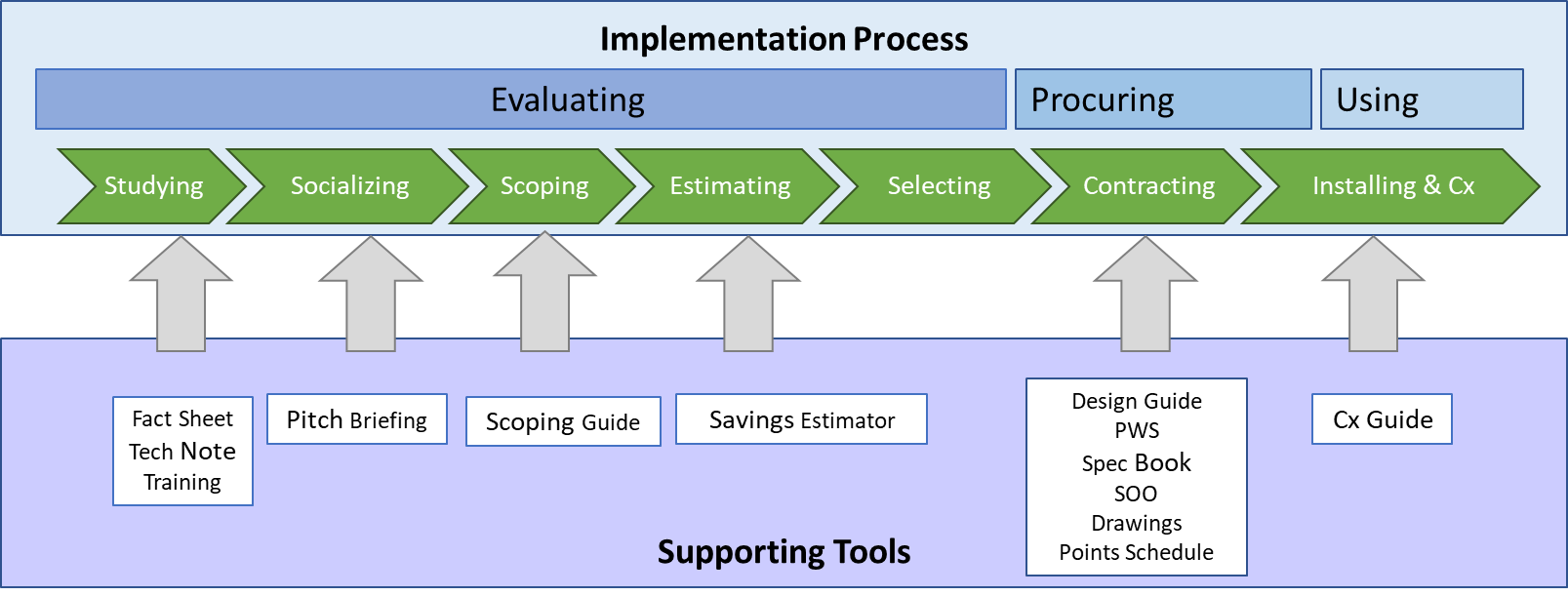


Figure : Implementation Support Suite of Tools



*Figure 3: Retrofit Implementation Process with Supporting Tools*

The ‘Technical Note’ document summarizes the findings of the original field demonstration project. It is recommended that it be reviewed to help decide if the retrofit is worth pursuing and to assist in selecting which multizone units are candidates for retrofit. Its contents include a technical explanation on how the retrofit saves energy, where the demonstrations occurred, and what savings were achieved in the demonstration project as well as expected savings for typical retrofit applications.

# MULTIZONE SYSTEM TYPES

Although multizone systems employ older technology, thousands still exist in DoD facilities due to the high cost of replacing these systems.

A multizone system supplies several zones from a single centrally located air handling unit (AHU). Individual zone loads are met by mixing cooled, heated or bypass air with zone dampers at the air handling unit in response to individual zone thermostats to provide a customized air temperature to each space. A unique characteristic of a MZ system is that the AHU distributes conditioned air to each zone through individual duct sections dedicated to each individual zone.

There are three typical multizone configurations: conventional two-deck, bypass, and neutral deck. Each of these configurations has a supply fan that operates at a single speed delivering a constant volume of air and uses zone dampers to mix air streams in the desired proportions to maintain temperature in each of the zones. Multizone air handlers differ in the number of decks they have as well as the number and placement of heating/cooling coils. A brief summary of each configuration follows. For simplicity, the following descriptions assume each system has an AHU with a mixing box capable of economizer function and that the system does not have a return or exhaust fan.

## Conventional Multizone (Hot Deck | Cold Deck)

The conventional multizone schematic and key features are provided in Figure 4. Return air and outside air are introduced into the AHU through the mixing box. Air is passed over parallel heating and cooling coils, located in the hot and cold decks, respectively. Downstream of the hot and cold decks is a linked pair of zone dampers, with one damper for the hot deck, and the other damper for the cold deck. Zone damper pairs are two dampers mechanically linked and offset by 90° such that as a damper opens to one deck, it closes its linked deck damper proportionally in reciprocal fashion. There are multiple pairs of these zone dampers, one set per zone. Each deck discharge temperature is maintained by a coil control valve that is informed by the deck discharge temperature sensor. As the demand for zone cooling increases, the zone cold deck damper opens, and the hot deck damper closes in proportion to maintain a constant airflow to the zone. The reverse happens when demand for cooling decreases.

|  |  |
| --- | --- |
| CONVENTIONAL MULTIZONE | |
| * 2 Decks; 1 hot, 1 cold * Heating and cooling coils in respective decks * Both decks typically operated continuously, even when heating/cooling not needed * Retrofit efficiency strategies include seasonal deck shut off, i.e., running only the hot deck in winter and only the cold deck in summer (but has led to mold issues and reduced comfort), and decoupling zone dampers to operate them independently (but is difficult and costly). |  |

Figure : Conventional Multizone Schematic and Key Features

## Hot Deck Bypass Multizone (Texas multizone)

The bypass multizone schematic and key features are provided in Figure 5. Return air and outside air are introduced into the AHU through the mixing box. Air is passed over the cooling coil in the cold deck and bypassed around the cold deck through the bypass deck (where there is no coil). Downstream of the cold and bypass decks is a linked pair of zone dampers (with one damper for the hot deck, and the other damper for the cold deck). Zone damper pairs are two dampers mechanically linked and offset by 90° such that as a damper opens to one deck, it closes its linked deck damper proportionally in reciprocal fashion. There are multiple pairs of these zone dampers, one pair per zone. The cold deck discharge temperature is maintained by modulating a coil control valve informed by the deck discharge temperature sensor. As the demand for zone cooling increases, the zone cold deck damper opens, and the zone bypass deck damper closes in proportion to maintain a constant airflow to the zone. If additional heating of the supply air is required for a zone, a heating coil is located downstream of the zone dampers in each duct serving each zone.

|  |  |
| --- | --- |
| BYPASS MULTIZONE (TEXAS STYLE) | |
| * 2 decks: Cold and Bypass * No Coil in Bypass Deck * Heating coil typically in each zone duct (allows heating in only zones that need it) * Uses unconditioned air (e.g., recirculated and outside air) in bypass deck for partial “free heating” when not economizing, especially useful in hot/humid climates that cool to 48-52°F for dehumidification needs. * More efficient than Conventional Multizone (avoids simultaneous heating and cooling) * More coils to maintain |  |

Figure : Bypass Multizone Schematic and Key Features

## Neutral Deck Multizone (Three-deck multizone)

The neutral deck multizone schematic and key features are provided in Figure 6. Return air and outside air are introduced into the AHU through the mixing box. Air is moved through parallel heating and cooling coils and an additional bypass path to a linked set of zone dampers. AHUs with three decks may have two damper pairs for each zone (with two actuators, one for each pair) or an assembly of three linked dampers with a single common actuator to orchestrate the mixing of the three available decks. The key feature in the triple deck arrangement is that the hot and cold deck are not open at the same time and the neutral deck is reciprocal to the operating conditioned deck. Each of the damper actuators receives its signal from its respective zone controller. The hot and cold deck discharge temperatures are maintained by their respective control valves informed by the deck discharge temperature sensor for each coil. As the demand for zone cooling increases, the cold deck damper opens and the mechanically linked bypass damper closes. As the demand for zone heating increases, the hot deck opens and the mechanically linked bypass damper closes.

|  |  |
| --- | --- |
| NEUTRAL DECK MULTIZONE | |
| * 3 Decks: Hot, Neutral, and Cold * Neutral Deck has no coil and introduces mixed air (recirculated and outside air) * Uses unconditioned air (e.g., recirculated, and outside air) in neutral deck for partial “free heating” when not economizing, especially useful in hot/humid climates that cool to 48-52°F for dehumidification needs. * More efficient than Conventional Multizone (avoids simultaneous heating and cooling) |  |

Figure : Neutral Deck Multizone Schematic and Key Features

# RETROFIT CONSIDERATIONS

Each retrofit system will have unique characteristics and issues that can be difficult to anticipate. This Design Guide addresses various characteristics and issues but is primarily intended to cover the basic requirements for a MZ-VV controls retrofit.

## Implementation approaches

The approach to the retrofit project will depend in part on the local context of the retrofit in relation to current or previous work, where there are three scenarios:

* **Incremental Retrofit.** (VV added to DDC project underway) When a DDC upgrade project is already in the planning phase, an incremental retrofit consists of adding this variable volume technology to the pre-existing project plan and includes the addition of a VFD, air flow station and controls programming.
* **Partial Retrofit.**  (VV after previous DDC project) This is basically the same as an ‘Incremental Retrofit’ described above except it is executed as a separate (i.e., brand new) project on a system that already has DDC. The scope can vary depending on project-specific requirements and the inclusion of additional functions and capabilities such as DCV.
* **Full Retrofit.** (New VV and DDC together) This converts an entire older HVAC control system (e.g., old pneumatic control system or other older control system) to DDC and incorporates the variable volume technology. The scope can vary depending on project-specific requirements and the inclusion of additional functions and capabilities such as DCV, economizer, scheduled on/off, etc.

## Additional Guidance

Guidance and specifications, beyond that contained in this Design Guide, may need to be added by the designer/specifier to address project-specific requirements. The ‘Scoping Guide’ describes a process to help identify potential additional project-specific requirements.

## Direct Digital Control System and Integration

Overall, consideration must be given to determining what new DDC-related devices may be required and which existing devices require replacement or can be re-used. If there is a DDC system in place, consider re-use of existing devices, wiring, conduit and control panels to reduce cost.

The designer/specifier must consider compatibility with any pre-existing open protocol technology/hardware along with interfacing the retrofit control system with a supervisory interface such as a UMCS front end, and the use of the installation’s (UMCS) IP network and the (local) building control network.

This may require the use of the following technologies and associated United Facilities Guide Specification (UFGS) sections:

* LonWorks with or without Niagara Framework: UFGS 23 09 23.01 – LonWorks Direct Digital Control for HVAC and Other Building Control Systems, or
* BACnet with or without Niagara Framework: UFGS 23 09 23.02 – BACnet Direct Digital Control for HVAC and Other Building Control Systems, and
* Tying the control system into a Utility Monitoring Control System (UMCS): UFGS 25 10 10 – Utility Monitoring and Control System (UMCS) Front End and Integration

Alternatively, a scaled down approach might include a Performance Work Statement (PWS) requirement such as: The control system must be an [extension of the existing control system][open implementation of LonWorks technology using CEA-709.1-C as the communications protocol and using LonMark Standard Network Variable Types as defined in LonMark SNVT List][open implementation of BACnet technology using ASHRAE 135 as the communications protocol and using standard ASHRAE 135 Input/Output Objects. All DDC Hardware must meet [UFGS 23 09 23.01 – LonWorks Direct Digital Control for HVAC and other Building Control Systems] [UFGS 23 09 23.02 – BACnet Direct Digital Control for HVAC and other Building Automation Systems][INSERT Currently Installed Direct Digital Control System Specification to be determined by the designer/specifier]

The PWS verbiage would need additional requirements defined to tie the retrofit control system into a UMCS supervisory front end. One approach is to include a PWS requirement such as: “The retrofit control system must interface with [a] [the pre-existing] [UMCS Name] UMCS as shown in the Points Schedule drawing. In addition/alternatively the PWS could require: [add verbiage requiring graphic schematic displays, show all I/O points, setpoints, operator adjustable settings, and operator configurable settings.]

## Other UFGS and References

Some aspects of the retrofit may necessitate additional project-specific requirements where other United Facilities Guide Specification (UFGS) or UFGS sections may help with the design and specification:

* TAB: UFGS 23 05 93 - Testing, Adjusting, And Balancing For HVAC
* Modulating Dampers and Valves: UFGS 23 09 13 – Instrumentation and Control Devices for HVAC
* Balancing Dampers: UFGS 23 30 00 – HVAC Air Distribution
* Ductwork Repair: UFGS 23 30 00 – HVAC Air Distribution
* Insulation: UFGS 23 07 00 – Thermal Insulation for Mechanical Systems

If partnering the MZ-VV retrofit with a control system renovation/upgrade, it is recommended to include and tailor the following specifications to meet the project-specific and site’s needs.

* UFGS 23 09 00 – Instrumentation and Control for HVAC
* UFGS 23 09 13 – Instrumentation and Control Devices for HVAC
* Cybersecurity Requirements: UFGS 25 05 11 – Cybersecurity for Facility-Related Control Systems

The above specification references can be found at the Whole Building Design Guide website (WBDG.org).

Additional references that informed this Design Guide are included in Appendix F – Bibliography.

# RETROFIT PROCEDURE

This section describes a recommended procedure to help identify, prioritize, select, design, and specify multizone systems/units for retrofit. Included here are various selection criteria, description of a ‘Scoping Guide’ spreadsheet tool and an ‘Savings Estimator’spreadsheet tool, followed by a list of contract package documents and descriptions of these documents. Installation and commissioning guidance is also described.

## Deal Breakers

Some Multizone systems are not good candidates for retrofit:

* Older units with less than 10 years of life left. Consider if the unit can be repaired or refurbished so that it will last at least 10 years. This is essentially a judgement call where the maintenance staff may have beneficial input. If the unit does not have 10 years of life left the return on investment (ROI) will be poor. While a controls retrofit can improve unit performance it cannot be expected to remedy underlying equipment problems or related issues such as humidity/moisture problems. Other circumstances could eliminate a unit/system as a candidate such as asbestos which can be cost-prohibitive to test/remediate. Unit condition is discussed more in Section 6 and in the ‘Scoping Guide’ spreadsheet described below and in Appendix D.
* Units with insufficient heating/cooling capacity, more specifically units with any incurably ‘starved’ zones. A starved zone is one that does not have sufficient heating or cooling capacity supply and therefore the zone cannot be thermally satisfied (A re-balance of the system may remedy this problem). A starved zone is always (or very often) calling for full heating or full cooling. In a multizone system this means that the zone damper will be full open to either heating or cooling (depending on what the zone is ‘starved’ for) often if not always. An example is a small zone, like a communications closet with a thermostat in the space, that has a low cfm requirement but that can evolve over time into a zone starved for cooling as communications equipment is added. If the unit has one or more starved zones, then the variable volume function of this technology will not save much if any energy. This is because the control system adjusts fan speed based on the most critical (most open) zone damper, where fan speed is decreased until one of the (multiple) zone dampers is at or very near full open position. Similarly, if any one zone damper is in the more than 95% open position the supply fan speed increases. A zone damper that is 100% open will cause the fan speed to gradually increase to maximum speed. If the zone damper remains at 100% open indefinitely, the zone is starved, and the fan will remain at 100% speed and not save energy.
* Units unable to accommodate an air flow measurement array (AFMA). The typical requirement is 2 duct diameters of unobstructed distance upstream of the flow station and one duct diameter downstream but varies by manufacturer and the specific circumstances. Refer to Section 6.2.

## Project Scoping

A ‘Multizone Scoping Guide’ spreadsheet tool is available to facilitate an assessment of the multizone system and AHU including condition, operational status, and suitability for retrofit. The Scoping Guide defines ‘Preliminary Scoping’ and ‘Full Scoping’ information and data. The information and data obtained can also help with the design and specification of units selected for retrofit. An overview of the **‘**Scoping Guide’ is in Appendix D.



Figure : Scoping Guide

## Economic Estimator

A ‘Savings Estimator’ spreadsheet tool is available to help perform an economic analysis of a MZ retrofit on multiple units. The estimator is designed to evaluate the energy and cost impact of implementing the retrofit and provide a payback analysis to assist in justifying the retrofit. An overview of the ‘Savings Estimator’ is in the appendix.



Figure : Retrofit Savings Estimator

## Select Systems/Units

Candidates for the retrofit that have been evaluated using the ‘Scoping Guide’ and are shown to have acceptable payback in the economic ‘Savings Estimator’ should be combined into contract packages for solicitation and award. The number of contracting packages should be kept to as few as possible to lower implementation costs. Logical combinations include units that are located in the same building, as well as merging the variable volume retrofit with a pneumatic to DDC controls upgrade. In some cases, project funding is prioritized based on mission criticality. Review of the BUILDER mission dependency index might help identify high priority facility types that should be prioritized for retrofit.

## Assemble Contract Package

Project specific requirements will need to be identified and addressed by the designer/ specifier. Considerations to assist with various project specific design and specification selections are described in Section 6. Editable file formats for contract package documents are available at: WBDG website - Design Guide webpage: https://www.wbdg.org/ffc/army-coe/design-guides/multizone-variable-volume-design-guide.

Technical input to the contract package consists of the following:

* **Performance Work Statement (PWS**). Appendix A contains a template/sample PWS. The PWS should be tailored to meet the project specific requirements of the particular installation and system. The designer/specifier may choose to list the UFGS & UFCs referenced in this Design Guide and describe any other requirements (local design requirements, TAB effort, refurbishment identified during Scoping/inspection, servicing of dampers/actuators, etc.). Coordinate the PWS and local site boiler plate requirements with requirements currently listed/shown in the ‘General Notes’ on the ‘Title Sheet’ of the control drawing set.
* **Control Drawings**. A set of template control drawings for the MZ-VV retrofit are available for all unit types including with or without a return fan[[2]](#footnote-2). Designer/ specifier selections in the drawings are indicated by square brackets [ ], and drawings must be added or removed to adequately show the retrofit. A recommended drawing set consists of the following drawings:

• **Title Sheet / Index**. Coordinate the ‘General Notes’ on this drawing with local contracting requirements.

• **Symbols/legend/abbreviations/acronyms**.

• **As-Builts** (Pre-existing schematics, Floor plan, ductwork, etc.). Obtain as-builts for the specified system. Provide any additional pre-existing documentation that can assist the contractor in executing the retrofit including commissioning reports, equipment data sheets, TAB reports, and any other relevant documentation.

• **Additional drawings**. Consider using marked up as-builts or supplemental drawings to show (as applicable) locations of occupancy sensors, CO2 sensors, space sensor modules (i.e., thermostat) especially if existing ones are to be replaced and/or new ones are to be provided by the contractor. The ‘Schedules’ drawing in the control drawing set provided as part of this Design Guide is intended to help provide details for these devices, but floor plan drawings are best to indicate locations.

• **Control schematic**. Edit to be project specific as required/needed.

• **Ladder diagram**. This is sometimes referred to as a circuit or wiring diagram that shows control system equipment interlocks and interfaces.

• **Control Logic Diagrams (CLD)**. These are intended to be unambiguous graphical descriptions of the control system sequence of operation.

• **Sequence of Operation (SOO)**. Insert project-specific sequence(s).

• **Control Schedules**. Complete the bracketed entries.

• **Points Schedule**. Insert project-specific Points Schedule(s).

• **Points Schedule Instructions**. See Appendix D of UFC 3-410-02 for Points Schedule instructions.

* **Sequence of Operation**. Appendix C contains template sequences for the various MZ configurations. Each sequence must be edited to be project specific. Guidance on project specific requirements and selections are discussed in Section 6 and in ‘Designer/Specifier Notes’ in each sequence.
* **Specifications**. Appendix B contains a template/sample specification or ‘Spec Book’ for the retrofit. There are three parts or sections in the Spec Book:
  + - Part 1 - General – Specifies particular requirements about the materials and workmanship of the project.
    - Part 2 - Products – Specifies the quality requirements for the products that are being provided as a part of the project.
    - Part 3 - Execution – Specifies how the products described in part 2 are incorporated into the work.

The ‘Spec Book’ defines requirements for a Performance Verification Test (PVT) Plan and refers to a PVT Plan template. This template was developed as part of the demonstration project and is specific to the MZ-VV (retrofit) technology. The specifier/designer should include the tailored template in the contract documents, perhaps as part of the PWS, and make a copy of the template spreadsheet, in electronic format, available to the contractor.

Additional requirements and specification sections may be needed/added at the designer's discretion. Other specifications, as might be needed to meet project-specific requirements, are listed in Sections 4.3 and 4.4.

In the Spec Book designer/specifier selections are shown in square brackets [ ] to indicate where designers must make tailoring decisions. It also helps the designer find designer sections using text search and replace functions.

Project specific requirements and related specifications, selections and considerations are described in Section 6.

* **Resilience Purchasing Justification** (if needed). Appendix F provides a sample statement of the resilience improvements that result from the energy savings of the retrofit. Some commands prioritize purchasing efforts that support resilience.

## Install And Commission System

A MZ-VV retrofit project will generally be of limited scope and resources. This is the case because it involves only the HVAC control system (not a large construction project often associated with a commissioning team/effort) and may not include very many MZ units/systems. Still, commissioning and Quality Assurance (QA) is important to help ensure a successful project/system that is complete and functions properly.

Installation and commissioning requirements/elements leading to acceptance of a completed project include but are not limited to; coordination/meetings with the contractor, review/approval of submittals, start-up and performance verification tests, documentation/records/as-builts, and training.

Installation and commissioning requirements/elements are provided in the ‘Commissioning Guide’ spreadsheet tool in checklist and summary format to help QA personnel expeditiously execute a retrofit project. The expectation is for minimal document preparation/development time and effort on the part of the QA staff. Your greatest investment of time/effort will likely be participating in the performance verification test which is the ultimate validation of the success of the retrofit.

# PROJECT-SPECIFIC REQUIREMENTS

The designer/specifier must identify project specific requirements. Some things to consider are described in this section.

## Outside Air Flow Control Options

Pre-existing constant volume MZ systems were likely designed and installed where the outside air damper was set to a fixed position to obtain the proper outside air quantity for ventilation or make-up air. Conversion to variable volume requires the use of an updated control scheme to maintain proper outside airflow while the AHU fan speed varies.

Most MZ units targeted for this retrofit (older units) will only have one outside air duct. A newer unit may have two outside air ducts, one for economizer and one for OA ventilation or makeup air. The designer/specifier should take this in account in the design/specification of the retrofit, specifically with regard to the control schematic drawing, the sequence of operation, and the Points Schedule.

Consideration must be given to the air carrying capacity of the outside air ductwork. For systems with a low outside air capacity (e.g., those without an airside economizer), control logic is needed to ensure that the minimum fan speed increases if ventilation requirements are not met when the outside air damper is fully open. The default sequences of operation include this control logic.

The template sequences include three OA flow control options from which to choose, and each calls for specification and installation of an outside air flow measurement array. The three flow control schemes are:

* Fixed OA flow control
* Demand controlled ventilation - based on occupancy sensors
* Demand controlled ventilation - based on CO2 sensors

Each of these is described below.

## Fixed OA Flow Control

Fixed outside air flow control uses an airflow measurement array (AFMA) to measure outside air and the DDC Hardware adjusts the OA damper to maintain outside air at a fixed flow setpoint. In addition to DDC Hardware and damper actuator, this control scheme requires the use of an AFMA as described in Section 6.2.

This control strategy is the simplest to implement and easiest to maintain, the energy savings will be somewhat lower than demand controlled ventilation.

**Requirements**:

In the Sequence of Operation select the type of ‘OA Flow Control’ bracketed option ‘Fixed Flow Setpoint’.

In the Points Schedule drawing: 1) Show the OA flow setpoint. 2) Specify the cfm flow range of the AFMA corresponding to the fpm range based on the duct dimensions at the location of the AFMA.

## Demand Controlled Ventilation (DCV)

DCV is a control function that likely does not pre-exist with older MZ units and the designer/specifier may choose to incorporate it. A DCV control scheme adjusts fresh air ventilation (using the outside air flow measured at the AFMA to adjust the outside air damper) based on space occupancy. The template control drawings accommodate DCV functionality through the use of occupancy (OCC) or CO2 sensors. Note: Use of CO2 sensors in Army and Air Force applications may require approval by the Authority Having Jurisdiction.

DCV can provide significant energy savings by adjusting ventilation during periods of partial occupancy. Limiting the OA quantity based on occupancy will save more energy than fixed OA flow, but is a more complex control strategy. Plus, CO2 sensors can be problematic as they are reported to be prone to calibration errors which can cause operational/performance issues.

Each MZ control system Sequence of Operation in the appendix includes a section entitled ‘Outside Air Flow Control’) with bracketed options for DCV where the specifier/designer must select the type of DCV: Occupancy Sensor or CO2 Sensor.

Note that DCV using *both* OCC sensors and CO2 sensors is possible but not explicitly included in the sequence. This variation is left to the designer. Also note that for OCC sensor based DCV, the sequence shows OA flow setpoint adjustment for two conditions: when any OCC sensor senses occupancy and when no OCC sensor senses occupancy. OA flow setpoint adjustment for more than these two conditions (e.g., one for each of multiple OCC sensors) is possible. This variation is left to the designer.

ASHRAE Standard 62.1 defines Dynamic Reset as: “The system may be designed to reset the outdoor air intake flow and/or space or ventilation zone airflow as operating conditions change.” To accomplish this, the Sequence of Operation OA flow setpoints (OA-F-SP) must be selected for the associated space demand (for ventilation) as indicated by the OCC and/or CO2 sensor signals. While ASHRAE 62.1 is the ultimate authority, guidelines on selecting the OA flow setpoints as part of Dynamic Reset are described in Trane Engineering Newsletters Volume 34-5 (2005) and Volume 49-3 (2019). Note that Volume 34-5 is somewhat outdated but is a useful primer on DCV basics.

DCV based on:

* OCC sensor: Occupancy sensor(s) detect occupant presence in spaces served by the AHU and signal the control system to adjust outside air quantity. Occupancy sensors must be ceiling-mount and generally not have obstructions blocking the view of the sensor in order to get reliable readings. Passive Infrared (PIR) sensors are very dependent on direct line-of-sight. Ultrasonic sensors are much less sensitive to obstructions.
* CO2 sensor: CO2 sensors monitor CO2 level in units of parts per million (ppm) and signal the control system to adjust outside air quantity.

**Requirements**:

In the Sequence of Operation select the type of ‘OA Flow Control’ based on bracketed options; Occupancy Sensor DCV or CO2 sensor DCV.

In the Sequence of Operation select the sensor statuses and/or CO2 levels (ppm) and the corresponding OA flow setpoints. Refer to the DCV discussion above and Dynamic Reset in ASHRAE Standard 62.1.

OCC sensor: List each OCC sensor in the control system drawing schedule ‘Zone Sensor Schedule’ by placing an ‘X’ in the ‘OCC SENSOR’ column. Indicate the type of occupancy sensor required in the control system drawing schedule in the ‘OTHER’ column of the ‘Zone Sensor Schedule’

CO2 sensor: List each OCC sensor in the control system drawing schedule ‘Zone Sensor Schedule’ by placing an ‘X’ in the ‘CO2 SENSOR’ column.

In the Points Schedule drawing specify the cfm flow range of the AFMA corresponding to the fpm range based on the duct dimensions at the location of the AFMA.

Note: For minimum OA control, as the OA damper is opened, the relief air damper should not need to be opened unless the OA requirement for the space significantly exceeds the exhaust and pressurization requirements. For economizer mode, at a minimum, the relief air damper command should be slightly offset (closed) relative to the RA damper to make sure OA is not being pulled into the building through the Relief Air Duct. This is especially important if there is no return fan or relief fan, and the system is relying on duct static pressures at the relief air plenum and mixing box to avoid uncontrolled intake. Some designers use a space static pressure sensor, others use relief plenum pressure to control the damper position. A third way is to measure the flows (& pressures) during TAB when the AHU fan is at max flow and min flow to determine the min and max position for the relief damper during economizer. This application requires a designer and TAB contractor to work in unison during setup. If this effort is desired, make sure there is language in the PWS to require this coordination.

## Airflow Measurement Array (AFMA)

Maintaining outside airflow introduced in the AHU is critical for proper ventilation and/or makeup air especially as the VFD varies the total system airflow. Control of the OA can be accomplished using an Air Flow Measurement Array (AFMA) installed in the outside air duct along with direct digital control (DDC) Hardware to modulate the AHU damper actuators.

The existing MZ AHU almost certainly will not have a pre-existing AFMA. Care must be taken to verify that the system can accommodate the installation of an AFMA. If not, the unit is not a good candidate for retrofit.

Installing an AFMA that provides reliable measurement requires it to be strategically located/installed in the airflow, depending on what kind of ducting and equipment is near the AFMA. Different AFMA vendors have different requirements based on their technology and have installation requirements that specify optimal placement. These requirements typically use distances in units of circular duct diameters, up and downstream of obstructions, as a dimensional reference, which can be calculated for rectangular ducts using the following equation:

Example duct obstructions and recommended distances of these obstructions from the AFMA for one manufacturer is shown in Figure 4.

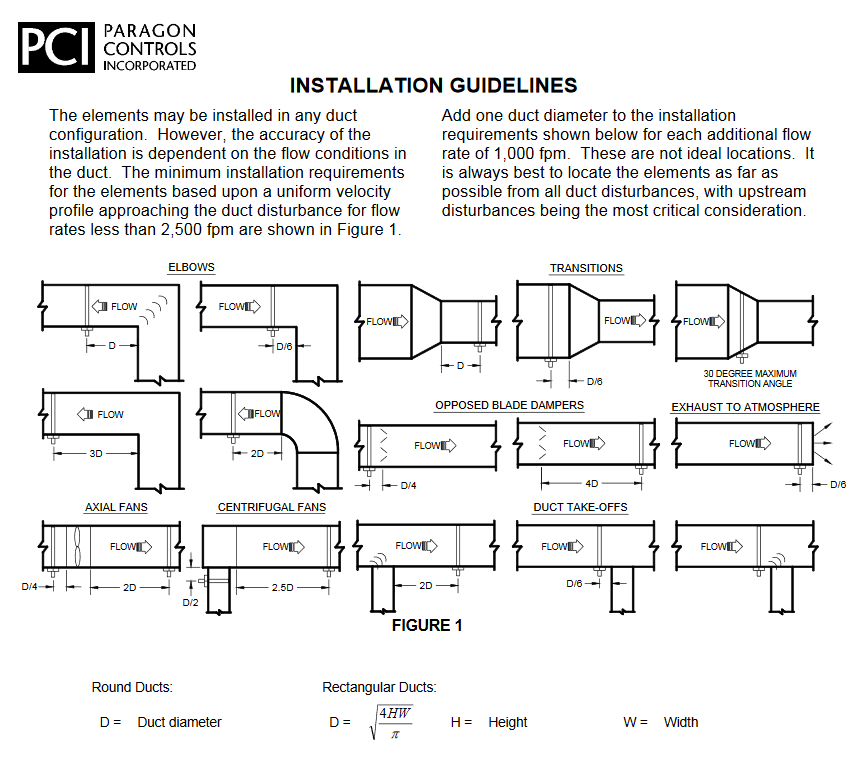


Figure 9: AFMA Installation Guideline Example

An air handler with limited access to the OA intake or limited up and downstream distances from obstructions need not be ruled out. Consult with an airflow measurement array manufacturer for possible solutions.

A multizone can potentially be retrofitted without the use of an AFMA but is not advisable; primarily because it will require a level of attention including time, effort and cost that may be beyond what can be expected in a typical commercial HVAC environment and risks pre-mature failure as the system ages. The basic approach consists of characterizing the outside airflow rate based on OA damper position and AHU fan speed. This is described in Trane Engineers Newsletter Volume 42-2 under paragraph “Proportional control of OA damper”. Where the position of the outdoor air damper is modulated in proportion to the changing supply fan speed. Trane points out that this is a relatively inexpensive solution and thus potentially used in smaller AHU applications although it is not perfectly accurate over the entire range of airflows, since damper performance is nonlinear, nor does not account for outside influences like wind or stack effect.

Two typical styles of AFMAs are used.

* Pitot Tube Style. Less expensive but requires a minimum velocity of 400 feet/minute velocity for stable accurate measurement. Some manufacturers say they can read at lower velocities, but care should be exercised when selecting these units because the installation requirements are more stringent and may require airflow straighteners (e.g., honeycomb devices) and/or long ‘straight-duct’ distances up and downstream of the AFMA.
* Electronic Style. This type is generally more expensive and more accurate than the pitot tube type at lower velocities (fpm) which can be beneficial in a variable airflow system. As such, it is recommended in applications where the outside air duct is large/sized for full AHU fan cfm capacity (i.e., has economizer capability) because the OA duct will be large and therefore the airflow velocity can be quite low when the economizer is not ‘on’ and the system is operating at the minimum outside air flow setting.

Airflow straighteners may be required if there is not sufficient length (distance) of straight run ductwork up and downstream of the AFMA. Consult with the manufacturer of the preferred basis of design to determine if straighteners are needed. Installation of straighteners may be impractical due to access limitations.

For locations where outside air temperatures are extreme, specify an AFMA that can operate under the full range of expected temperatures.

**Requirements**: Verify that the OA ductwork has sufficient space to accommodate an AFMA. Refer to Appendix B – ‘Specification Book’ to select pitot tube or electronic AFMA. In the Points Schedule drawing specify the cfm flow range of the AFMA corresponding to the fpm range based on the duct dimensions at the location of the AFMA.

## Space Humidity (Dehumidification) Control

A multizone unit can present humidity related concerns. Air moving through a bypass or hot deck is not exposed to a cooling coil and therefore undergoes no latent heat transfer and thus no moisture removal. In certain situations and climates, this presents the potential for moisture problems. For example, during warm periods (e.g., summer) while it is relatively cool outside with a high outdoor dewpoint temperature (e.g., while it is raining) space conditions can become humid when a significant amount of air is directed through the bypass or the hot deck.

The demonstration systems were monitored for comfort, using criteria from ASHRAE Standard 55, and the space comfort conditions proved similar for the pre-retrofit MZ as compared to the post retrofit MZ. This does not mean the retrofit alleviates humidity concerns but suggests they will not be worse with the retrofit.

In the event of humidity/moisture problems, the maintenance section of this Design Guide, Section 6.15, describes operator adjustable settings that can help. Refer to Section 6.15, but in summary these settings define conditions where the cooling coil valve is closed to help prevent energy waste (when there is little to no call for any zone cooling), and these settings can be adjusted for each of the three different types of MZ.

A bypass MZ, which has individual zone heating coils, can incorporate a dehumidification control sequence of operation. This sequence is included as a designer/specifier option in the template sequence.

Conventional and neutral-deck type multizones, due to the absence of individual zone heating coils, do not have a sequence of operation option for dehumidification control.

**Requirements**: If dehumidification control is desired for a bypass MZ, select the bracketed option in the sequence of operation, make sure that the specification book includes relative humidity sensors, indicate (using x’s) in the Space Sensor Module Schedule (in the template control drawings) for the spaces that require relative humidity sensors, and edit the template points schedule to include the Space Humidity Control optional points.

## Damper Actuators – for the AHU mixing box

Typically, the AHU contains three dampers that operate in unison; the outside air (OA), return air (RA), and relief air (RLA) dampers. Although there are 3 dampers, the pre-existing system may have only 2 actuators with the OA and RA dampers actuated by a single actuator because these dampers are mechanically linked.

Pre-existing actuator(s) may need to be replaced to be compatible with DDC hardware or simply as a pre-emptive measure to replace aging and or failing actuators. Consider replacing pneumatic actuators with electric actuators. This is strongly recommended for a ‘Full Retrofit’ such as the replacement of a pneumatic control system.

**Requirements**: Consider replacing existing actuators with new ones. Consider replacing pneumatic actuators with electric actuators to potentially reduce maintenance requirements (for ancillary air supply equipment). Check with maintenance personnel for input. If the actuators are in good condition, ensure all actuator/damper crankarms, linkages, damper blades, and jackshafts are tight.

## Damper Actuators – for the zone dampers

Pre-existing actuator(s) may need to be replaced to be compatible with DDC hardware or simply as a pre-emptive measure to replace aging and or failing actuators. Consider replacing pneumatic actuators with electric. This is strongly recommended for a ‘Full Retrofit’ such as the replacement of a pneumatic control system.

**Requirements**: Consider replacing existing actuators with new. Consider replacing pneumatic actuators with electric actuators to potentially reduce maintenance requirements (for ancillary air supply equipment). Check with maintenance personnel for input. If the actuators are in good condition, ensure all actuator/damper crankarms, linkages, damper blades, and jackshafts are tight.

## Fan Motors

Typically, the existing fan motor can be reused when a VFD is added to the system, but it is best to consult with an electrical engineer or other motor specialist. Things to consider:

* Motor age. This may be a good time to replace the motor if it is nearing the end of its useful life.
* Efficiency. A more efficient replacement motor may pay for itself over the life of the system and use less energy thus reducing the carbon footprint of the system. The efficiency of a pre-existing motor should be on the motor nameplate or obtainable from the manufacturer.
* Downsizing (or upsizing). It may be worthwhile to measure the full load amps on the current motor, particularly if it is to be replaced, to help specify the required motor size.
* Heat. Some older motors may tend to overheat when operated at a lower rpm. A general conservative rule is to operate an older motor at no less than 50% of its maximum rated speed. A premium efficiency replacement motor that meets NEMA MG1 requirements can be operated at lower speeds, potentially as low as 35% of its maximum. An ‘inverter duty’ motor can be operated at even lower speeds (but see the paragraph below that discusses inverter duty).
* Insulation breakdown can occur in motors operated by VFD if the motor insulation class is less than Class F.
* Noise, vibration, and bearing problems are other potential problems that may be encountered when using an older motor with a VFD.

The Department of Energy (DOE) “PREMIUM EFFICIENCY MOTOR SELECTION AND APPLICATION GUIDE” is a useful information source including energy savings equations for comparing a more efficient motor to a less efficient motor: <https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf>

In general, a fan motor in an HVAC application does not require a top-of-the-line "inverter-duty" motor as these are very expensive, typically 3 to 4 times the cost of a premium efficiency motor. Note that there does not appear to be an industry standard definition for "inverter-duty" motor and that premium-efficiency motors often carry the designation "inverter-ready" or "inverter-friendly" although terms like "inverter-ready" have different meanings among motor manufacturers.

**Requirements**: If the fan motor(s) is to be replaced specify a premium efficiency motor that meets NEMA-MG1, Motors and Generators Standard, requirements. A recommended motor specification is in Appendix B – ‘Specification Book’.

## Variable Frequency Drive (VFD)

A VFD is required for the supply fan, and for the return fan if there is a return fan in the system. The VFD specification in Appendix B may be used. It was developed as part of the MZ-VV demonstration project with the intent of being a simplified version of the DoD UFGS VFD Specification. The designer/specifier may choose instead to use a local site preferred specification or the UFGS from the WBDG website; UFGS 26 29 23 ‘Adjustable Speed Drive (ASD) Systems Under 600 Volts’.

If the building has an existing networked DDC system and there is a desire to add the VFD to that system, then the specification should include a network interface requirement compatible with the site-preferred communications protocol. Both the Specification Book in the appendix and UFGS 26 29 23 contain a network interface requirement, with designer selection of the protocol required. While an open communications protocol is preferred such as LonWorks or BACnet, the pre-existence of a proprietary (non-open) communications protocol may necessitate use of the pre-existing protocol.

The design should also call for the required control input/output (I/O) points hardwired to the VFD with VFD hardwired I/O minimally consisting of:

* Fan Start/Stop
* Fan Status
* Fan Speed Command

These I/O points are shown in the template Control drawings that accompany this guide[[3]](#footnote-3).

**Requirements:** A recommended VFD specification is in Appendix B – Specification Book. Consider the need to include a network interface and if so, the communications protocol to be specified.

## Occupancy Modes And Schedules

The Sequence of Operation describes the occupied/unoccupied control strategy. The template control drawings have an occupancy schedule that must be tailored to project requirements.

**Requirements**: Indicate the occupancy schedule in the Template Control Drawings.

## Night Stat

Historically a night stat is used to turn the system on after hours if the temperature at the location of the night stat drops too low. It is a pre-emptive action to prevent freezing of equipment or overly cool spaces. The night stat is typically located near an entryway or other location susceptible to getting cold. The night stat is shown as BLDG-T hardware device on the control schematic. The night stat can be a space sensor module that performs no control function other than to transmit temperature to the DDC system which acts on this information. The night stat function is a bracketed option in the Sequence of Operation.

A night stat is less necessary when the zone Space Sensor Modules (SSMs) (commonly referred to as thermostats), are performing similar function as that which is currently specified.

**Requirements**: Decide if: Retain or delete BLDG-T device in control schematic drawing and Points Schedule. Indicate location of BLDG-T device.

## Fan Pulleys & Belts

Fan pulleys and belts transmit power from the motor and VFD to the fan, and the performance of the system and retrofit are affected if there is damage to the belt or pulley or if there is misalignment.

**Requirements**: Determine the condition of the fan drive pulleys and belts and replace as part of a maintenance action.

## Space Sensor Module (SSM) and Space/Zone Sensors

Consideration should be given to the type and functionality of temperature sensors, space sensor modules, and related instrumentation.

Space Sensor Module (SSM). The SSM is often historically referred to as a ‘thermostat’. The term SSM was introduced in UFGS 23 09 13.

SSM functionality and features should include a temperature display, user/occupant setpoint adjustment capability, and night setback override button used to override the current ‘mode’ to place the system into occupied mode. Additional sensors contained in the SSM might include relative humidity (RH) and carbon dioxide (CO2) sensors. These should be used where applicable or desired by the local facility. RH sensors are recommended to be included in the SSM to serve as a maintenance and system performance diagnostic tool. On cool but humid days (e.g., when it is raining) the system may exhibit higher than usual humidity, but this did not present itself as a problem in the demonstration systems.

Demand Controlled Ventilation (DCV) located in zones/spaces are described in Section 6.1.2. While a CO2 sensor can be included in the Space Sensor Module, occupancy sensors should not reside in the SSM. PIR occupancy sensors should be ceiling mount for maximum viewing angle, not wall mount, otherwise they can be obstructed by cabinets, partitions, etc.

Duct-mount Point Sensors should be used where space is limited (zone discharge air temperatures) and where air stratification is not an issue.

Duct-mount Averaging Sensors should be used where air stratification is possible such as mixed air temperature sensing and downstream of heat transfer coils. Adequate space and access must be available for installation and should be maintained for proper maintenance.

Zone Discharge Air Sensors are strongly recommended. They are fairly inexpensive and can be very beneficial as a diagnostic/troubleshooting tool. A drawback is that one sensor per zone is recommended, and this may tax or exceed the analog input capacity of the DDC hardware (controller), particularly in the case where the pre-existing DDC hardware will be used.

**Requirements:** Determine if replacement zone sensors are required and adjust the design as needed.

## Air Filter Status Monitoring

Most DPWs do not use instrumentation to monitor air filter status. Instead, they replace filters on a time-based schedule. The designer should consult with the local DPW or maintenance activity for their preference. They may choose only to have a differential pressure gage installed for onsite/local visual indication of filter pressure drop. Or, where remote monitoring is desired, a differential pressure switch (DPS) should be shown and specified along with a differential pressure gage. The DPS should be shown on the control schematic with a connection to the DDC system. The DDC system must have an interface connection to the UMCS. The details of the interface will need to be identified and specified. The specifications must also call for selecting and setting the DPS setpoint along with performance testing the system operation.

**Requirements:** If air filter status monitoring is not required; delete it from the control schematic and delete the point from the Points Schedule drawing.

If air filter status monitoring is required, retain the symbol in the control schematic drawing and add these requirements to the spec book (from UFGS 23 09 13 ‘INSTRUMENTATION AND CONTROL DEVICES FOR HVAC’):

Differential Pressure Switch. Provide differential pressure switches with a user-adjustable setpoint which are sized for the application such that the setpoint is between 25 percent and 75 percent of the full range. The over pressure rating must be a minimum of 150 percent of the highest design pressure of either input to the sensor. The switch must have two pair of contacts and each contact must have a rating greater than its connected load. Contacts must open or close upon rise of pressure above the setpoint or drop of pressure below the setpoint as indicated.

Low Differential Pressure Gauge. Gauges for low differential pressure measurements must be a minimum of 3.5-inch (nominal) size with two pair of pressure taps, and must have a diaphragm-actuated pointer, white dial with black figures, and pointer zero adjustment. Gauge range must be suitable for the application with an upper end of the range not to exceed 150 percent of the design upper limit. Accuracy must be plus or minus two percent of scale range.

## Damper Position Feedback Option

Zone Damper Command (ZN-D-C) (i.e., the signal that the DDC Hardware sends to each zone damper) is used by the control strategy to adjust supply fan speed. Alternatively, Zone Damper Position (ZN-D-POS) feedback is an actuator feature where the actuator provides an output signal that represents its actual position in terms of how far it is open (or closed). This signal can be used as an analog input to DDC hardware. This feature is available with at least some manufacturer’s damper actuators, potentially as an option at additional cost.

The template control drawings and control sequences do not show/use the ZN-D-POS feedback feature but instead assume damper position is the same as the DDC hardware zone damper command (ZN-D-C).

An advantage to position feedback is that the control strategy can be based on the actual position of the zone dampers. If position feedback is preferred the template control drawings and control sequences will need to be changed to reflect this.

A disadvantage to ZN-D-POS feedback is that it may result in increased cost due to the increased analog input point count requirement of the DDC hardware controller potentially requiring a larger plant controller to accommodate the additional points. There is a potential trade-off given that it is also desirable to monitor the temperature of the air being delivered to each zone using zone discharge temperature sensors (as described in Section 6.11. Where pre-existing DDC Hardware is to be reused, if space is not available at the DDC Hardware for both damper position and zone temperature sensors, the designer is encouraged to choose zone temperature sensors because they are likely more beneficial.

**Requirements:** If ZN-D-POS is to be used the Control Schematic, Points Schedule, and Sequence of Operation need to be edited to accommodate the ZN-D-POS signals and functions.

## Testing, Adjusting and Balancing (TAB)

TAB of the renovated AHU and associated distribution system may or may not be required. It is advisable to consider TAB in the project but coordinate with the site/facility manager and maintenance staff. Prior reconfiguration of space utilization could affect TAB airflows needs/requirements. Plus, maintenance staff sometimes adjust balancing dampers and other equipment in response to heating and cooling trouble calls. As such, a re-balance of the system back to the original design could prove problematic.

TAB should be included if the system has a return fan. This is because the sequence of control and control drawings call for a fan matching (or speed matching) control scheme where the DDC Hardware sends a control signal to both the supply and return fan VFDs. These signals are usually presented in units of percent of maximum fan speed. The return fan command (RF-C) percent speed signal must be ‘OFFSET’ (by a fixed percentage) of the supply fan command (SF-C) percent speed signal. In other words, (typically) the RF speed command will be somewhat less than SF speed (by a fixed percent). For example, if the TAB contractor determines the OFFSET is 10%, when SF-C is 90%, RF-C is 90% - 10% = 80%. The TAB contractor must identify the RF-C fixed OFFSET such that over the full range of SF speeds the duct static pressure Is always positive at the inlet to the relief damper. This ensures that air is always relieved out the relief, not drawn in through the relief.

Typically, the relief damper is inside the AHU. The designer must consider the case where the relief damper is instead located external to the AHU such as in the space or one of the zones served by the AHU and the case where the relief damper has a backdraft damper.

The TAB contractor must provide the fixed OFFSET setting to the controls contractor.

TAB may be required if:

* Space airflow / load requirements have changed after the original installation. This might also necessitate designer re-calculation of the new loads and resulting zone airflows.
* Outside air flow requirement has changed
* Sequence of control is changed to incorporate demand controlled ventilation or airside economizer

Maintenance staff may have recommendations on the need for re-balancing.

**Requirements**:

If TAB is required add TAB language to the PWS, along with corresponding documents showing zone airflows. Describe site-specific TAB details and coordinate with the facility manager and/or maintenance staff regarding prior reconfigurations of the HVAC that could affect loads and airflow requirements. TAB should also be included if the system has a return fan.

## Maintenance Considerations

**VFD performance**

The energy savings with this technology/retrofit is heavily dependent on proper fan speed control, zone damper control and the assumption that no zone is always calling for full heating or full cooling (i.e., no ‘starved’ zones). Operator/maintenance staff should periodically inspect trend data to verify that the fan speed is not ‘stuck’ at 100% and to see if any zone damper is consistently full open or full closed.

**VFD minimum fan speed**

This technology includes the installation of a variable frequency drive (VFD), typically while retaining the pre-existing AHU fan motor. The guidance documents indicate a minimum AHU fan speed of 50%. This is a conservative setting based in part on the fact that a pre-existing (older) motor may tend to overheat while operating at a low rpm. If the motor is replaced/newer a minimum speed less than 50% (consider 35%) may be possible and potentially save additional fan energy.

**Return fan speed offset**

In a retrofit system with a return fan (RF) that uses a fan matching (or speed matching) control scheme, the control signal sent to RF VFD is identical to the control signal sent to the supply fan (SF) VFD, except the RF signal is OFFSET so that the RF signal is somewhat less than the SF signal so that the duct static pressure is always positive at the inlet to the relief damper. This helps to ensure that air is always relieved out the AHU relief, not drawn in through the relief. This can be tested by placing a lightweight object (e.g., sheet of paper or tissue) at the relief louver. At the full range of SF speed commands, the object should not be drawn into/against the louver. Relief air should always be directed outward. It is also possible there will be no air flow thus neutral static pressure at the relief. If the object is drawn into/against the louver, the air balance is incorrect. TAB is recommended to adjust the OFFSET setting so that air is not drawn into the relief.

**Zone Humidity & damper/valve position setpoints**

The MZ-VV control scheme saves energy by closing the cold deck cooling coil valve when no zones are calling for cooling or few are calling for very little cooling. Specifically, the baseline/default sequence closes the cold deck coil valve if \*all\* zone dampers are calling for 5% or less zone cooling. The cold deck valve return is re-enabled to allow for cold deck temperature control if \*any\* zone calls for 15% or more cooling. The cold deck provides for dehumidification (latent heat transfer) while it is performing its primary function of temperature control. As such, if the valve is turned off, as described previously, some increase in zone/space relative humidity may occur, especially on damp/rainy days. In a situation where zone/space relative humidity is a problem, the default settings of 5% and 15% can be adjusted (they are specified to be operator configurable). In the extreme, set them to 0% and 5%, respectively, to force the cold deck valve to remain on/enabled. These lower settings increase energy usage.

## Fire Alarm System (FAS) Coordination

DESIGNER NOTE: Determine if both supply and return air smoke detectors are needed and what they should signal. The Control Schematic default is that a Fire Alarm system (FAS) shut down relay is connected to the VFD. Most integrated FAS are microprocessor based with all smoke detectors, pull stations, etc. reporting back to a Fire Alarm Control Panel (FACP). Individual shutdown relays should be within 1 meter of each controlling device (starter, VFD, etc.) that disables the fan. There are some instances of hardwired smoke detectors to the fan controlling device, but they are becoming the exception rather than the rule. If there is an exception that the smoke detector is to be directly interlocked with the controlling device, then the specifier should resolve.

APPENDICES

APPENDIX A – PERFORMANCE WORK STATEMENT Template

Performance Work Statement (PWS) Template Editing/Tailoring Instructions

*These instructions describe editing/tailoring of the attached PWS template. Do not include these instructions in the final project-specific PWS.*

*The PWS content to be edited/tailored is highlighted in yellow and/or shown with (square) tailoring brackets [ ]. The PWS should be tailored to meet the project specific requirements in coordination with any installation-specific local contracting office requirements.*

*Attachments. Templates of all attachments listed in this PWS are available at the Whole Building Design Guide (WBDG) website,* <https://www.wbdg.org/ffc/army-coe/design-guides/>

*The recommended contract package content is more fully described in the ‘Multizone Variable Volume Controls Retrofit Design Guide’ including the ‘Specification Book’, Controls Design Drawings, and Sequence of Operation. A notable excerpt from the Design Guide: “Coordinate the PWS and local site boiler plate requirements with requirements currently listed/shown in the ‘General Notes’ on the ‘Title Sheet’ of the Controls Drawings set”.*

*PVT Plan Template attachment. The Performance Verification Test (PVT) template is an important attachment cited in the ‘Specification Book’ that the contractor will expect to be provided. The PVT Template is a workbook tab in the ‘Commissioning Guide’ MS Excel spreadsheet. It is labeled as a ‘template’ in the spreadsheet because the contractor is required per the ‘Specification Book’ to make it project specific.* *The contractor will need a copy of the Excel spreadsheet electronic file – therefore it is listed as an attachment to this PWS.*

*TAB attachment. If testing, adjusting, and balancing (TAB) is to be a required part of the project, as discussed in the ‘Design Guide’, include zone/diffuser airflow requirements and any other site-specific TAB details. Coordinate with the facility manager and/or maintenance staff regarding prior reconfigurations of the HVAC that could affect loads and airflow requirements. TAB should be included if the system has a return fan. The specifier must add verbiage/requirements to the PWS, as described in the ‘Design Guide’, to provide for balancing of a system with a return fan including identifying the OFFSET controls setting.*

*Additional Technical Requirements. Some possible additional project-specific requirements such as needed repairs are listed in this PWS as bracketed tailoring options. The ‘Design Guide’ and ‘Scoping Guide’ (described in the ‘Design Guide’) can help identify additional technical requirements.*

Performance Work Statement (PWS) – Template  
Multizone to Variable Volume Controls Retrofit

# Project Technical Requirements

## Technical Overview

This Performance Work Statement describes the technical requirements to perform a control system retrofit to convert existing constant volume multizone (MZ) system(s) to variable volume for energy savings. The project adds controls components and a new sequence of operation, with minimal alterations to the physical air handler or ductwork.

This project covers the renovation at selected multizone units. In addition to the AHU conversion itself, additional monitoring equipment will be installed [and the controls will be integrated into an existing Utility Monitoring and Control System (UMCS)].

## Location Information

The project includes the following systems:

* Installation: [INSERT INSTALLATION NAME]
* Building(s): [INSERT BUILDING NUMBER/NAME INFORMATION]

## Project System and Units Overview

[INSERT AHU QUANTITY] Air Handling Units (AHUs) are included in this project:

* [INSERT AHU IDENTIFICATION INFORMATION (E.G. AHU-#\_BLDG#-01)]
  + [INSERT AHU LOCATION INFORMATION (E.G. BLDG 123 IN MECHANICAL ROOM 234)]
  + Controls Protocol and Vendor: [INSERT BUILDING CONTROLS PROTOCOL (BACNET OR LONWORKS) AND PRE-EXISTING VENDORS]
* [INSERT AHU IDENTIFICATION INFORMATION]
  + [INSERT AHU LOCATION INFORMATION]
  + Controls Protocol and Vendor: [INSERT BUILDING CONTROLS PROTOCOL (BACNET OR LONWORKS) AND PRE-EXISTING VENDORS]
* [INSERT AHU IDENTIFICATION INFORMATION]
  + [INSERT AHU LOCATION INFORMATION]
  + Controls Protocol and Vendor: [INSERT BUILDING CONTROLS PROTOCOL (BACNET OR LONWORKS) AND PRE-EXISTING VENDORS]
* [INSERT IDENTIFICATION AHU INFORMATION]
  + [INSERT AHU LOCATION INFORMATION]
  + Controls Protocol and Vendor: [INSERT BUILDING CONTROLS PROTOCOL (BACNET OR LONWORKS) AND PRE-EXISTING VENDORS]
* [INSERT AHU IDENTIFICATION INFORMATION]
  + [INSERT AHU LOCATION INFORMATION]
  + Controls Protocol and Vendor: [INSERT BUILDING CONTROLS PROTOCOL (BACNET OR LONWORKS) AND PRE-EXISTING VENDORS]

## Basic Controls Retrofit Technical Requirements

Successful completion of the controls retrofit project for each system includes, but is not limited to:

* Install a supply fan variable frequency drive for each AHU in the project.
* [Install a return fan variable frequency drive variable frequency drive with associated hand-off-auto switch for the following AHUs in the project.]
  + [INSERT AHU INFORMATION FOR EACH UNIT WITH RETURN FAN]
* Install an Airflow Measurement Array (AFMA) for each AHU outside air ducts.
* Program the AHU per the sequence of operation.
* Integrate the new equipment to the existing building Direct Digital Controls (DDC) system per the points schedule in the design drawings.

## [Demand Control Ventilation Requirements

The following is demand control ventilation related project installation requirements includes, but is not limited to:]

* [Install occupancy sensors as specified and [per the design control drawings][as listed below].]
  + [INSERT AHU INFORMATION]
    - [INSERT BUILDING NUMBER AND ROOM NUMBERS]
* [Install CO2 sensors as specified and [per the design control drawings][as listed below].]
  + [INSERT AHU INFORMATION]
    - [INSERT BUILDING NUMBER AND ROOM NUMBERS]

## [Additional Technical Requirements

Additional project and unit specific installation includes:]

* [Remove existing and install new Space Sensor Modules and [per the design control drawings][as listed below]:]
  + [INSERT AHU INFORMATION]
    - [INSERT BUILDING NUMBER AND ROOM NUMBERS]
* [Remove existing and install new AHU damper actuators for the AHU mixing box for the following AHUs:]
  + [INSERT AHU INFORMATION AND ACTUATOR INFORMATION (E.G. AHU-#\_Bldg#-# RELIEF AIR, OUTSIDE AIR, AND/OR RETURN AIR]
* [Remove existing and install new zone damper actuators for AHU zone dampers for the following AHUs:
  + INSERT AHU INFORMATION AND ACTUATOR INFORMATION (E.G. ZONE 3, ANY OTHER IDENTIFYING INFORMATION]
* [Remove existing and install new [premium efficiency] fan motors for the following AHUs:
  + INSERT AHU INFORMATION AND FAN MOTOR INFORMATION (E.G. AHU-1, SUPPLY FAN 2 HP, RETURN FAN 1.5 HP]
* [Remove existing and install new AHU zone dampers, in kind, for the following AHUs:
  + INSERT AHU INFORMATION AND ACTUATOR INFORMATION (E.G. ZONE 3, ANY OTHER IDENTIFYING INFORMATION]
* [Remove existing and install new duct temperature sensors for the following AHU locations:]
  + [Probe type temperature sensor:
    - INSERT AHU AND SENSOR IDENTIFICATION INFORMATION (E.G. AHU-1, SUPPLY AIR TEMPERATURE SENSOR LOCATED AFTER THE SUPPLY AIR FAN]
  + [Averaging type temperature sensor:
    - INSERT AHU AND SENSOR IDENTIFICATION INFORMATION (E.G. AHU-1, MIXED AIR TEMPERATURE SENSOR LOCATED DOWNFLOW OF MIXED AIR PLENUM AND FILTER BANKS]
* [Provide Testing, Adjusting and Balancing (TAB) as indicated for the following AHUs:
  + INSERT AHU INFORMATION]

## All work shall be performed as indicated in this PWS, in accordance with the specifications and drawings attached to this PWS.

## Provide submittals required in accordance with the specifications attached to this PWS and to the work described in this PWS.

## Perform system start-up activities in accordance with the specifications attached to this PWS.

## Perform Performance Verification Test (PVT) in accordance with the specifications and procedures attached to this PWS.

## Training course must cover all aspects of the operation and maintenance of the installed and integrated system in accordance with the specifications attached to this PWS.

# Attachments

* Attachment 1: Project Specification Book, PDF format
* Attachment 2: Sequence of Operation, PDF format
* Attachment 3: Controls Design Drawing Package with associated as-built construction documents [ format]
* Attachment 4: Performance Verification Test (PVT) template, PDF format
* Attachment 5: Performance Verification Test (PVT) template electronic file, Microsoft Excel format

APPENDIX B – SPECIFICATION BOOK TEMPLATE

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

This specification book does not include DDC Hardware requirements. If the project requires DDC Hardware to be installed, please refer to installation specific requirements and consult with local design staff.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Part 1 – General**

* + 1. **Summary**

This section provides for the control system instrumentation and HVAC system equipment components and related requirements necessary for a complete and functional Multizone-to-Variable Volume controls retrofit.

Install hardware to perform the control sequences of operation as specified and indicated and to provide control of the equipment as specified and indicated.

Install hardware such that individual control equipment can be replaced by similar control equipment from other equipment manufacturers with no loss of system functionality.

Install and configure hardware such that the Government or their agents are able to: perform repair, replace, and upgrade individual hardware without further interaction with the installing contractor.

After becoming familiar with all details of the work, verify all dimensions in the field, and advise the Contracting Officer of any discrepancies before performing any work.

Provide a complete and functional system as indicated in the contract documents, refer to the Performance Work Statement (PWS) for additional information on required submittals, related specifications, and quality assurance requirements.

**1.2 Submittals**

1. SD-01 Preconstruction Submittals
   1. Project Schedule
2. SD-02 Shop Drawings
   1. DDC Contractor Design Drawings
   2. Draft As-Built Drawings
   3. Final As-Built Drawings
3. SD-03 Product Data
   1. Manufacturer’s Product Data
4. SD-06 Test Reports
   1. Start-Up Test Report
   2. Performance Verification Test Plan
   3. Performance Verification Test Report

Following each submission there will be a Government review period of [14] days unless otherwise specified. If a submittal is not accepted by the Government, revise the submittal and resubmit it to the Government within [14][\_\_\_\_\_] days of notification that the submittal has been rejected. Upon resubmittal there will be an additional Government review period.

**Part 2 – Products**

**2.1 Product Data.**

Provide manufacturer's product data sheets documenting compliance with product specifications for each product provided. Provide product data for all products in a single indexed compendium, organized by product type. Submit Manufacturer's Product Data on CD-ROM.

**2.2 Motors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

Determine if supply and/or return fan motor(s) are to be replaced. Typically, an existing fan motor can be reused when a VFD is added to the system but it is best to consult with an electrical engineer or other motor specialist. You can use the ‘Execution’ section of this spec or keyed note in the control system drawing to indicate/list the motor(s) that are to be replaced.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

[Motors must meet NEMA specifications for “Premium Efficiency Motor” and must be capable of being safely and reliably driven by a VFD. Motors must be selected based on high efficiency characteristics relative to typical characteristics and applications as listed in NEMA MG 10. In addition, continuous rated, polyphase squirrel-cage medium induction motors must meet the requirements for premium efficiency electric motors in accordance with NEMA MG 1, including the NEMA full load efficiency ratings. Motor must be open drip proof.]

**2.3 Variable Frequency Drive**

2.3.1 The VFD must control the speed of induction motor(s) by converting the input AC mains power to an adjustable frequency and voltage using Pulse Width Modulation (PWM).

2.3.2 The drive must have an efficiency of at least 96% at rated speed and load. The displacement power factor must be at least 0.95 under any speed or load condition.

2.3.3 Electrical and electromechanical components of the Variable Frequency Drive (VFD) must not cause electromagnetic interference to adjacent electrical or electromechanical equipment while in operation.

2.3.4 The drive must be suitable for operation in ambient air at 32 degrees F to 104 degrees F and up to 95 percent relative humidity, non-condensing, at rated load and switching frequency.

2.3.5 The drive must be designed to operate from the supply voltage plus or minus 10%, three phase, 60 Hz plus or minus 5%, and control motors with a corresponding voltage rating.

2.3.6 The VFD must be able to start into a spinning motor (flying start). The VFD must be able to determine the motor speed in any direction and resume operation without tripping. If the motor is spinning in the reverse direction, the VFD must start into the motor in the reverse direction, bring the motor to a controlled stop, and then accelerate the motor to the preset speed.

2.3.7 The system containing the VFD must comply with the 5% level of total harmonic distortion of line voltage and the line current limits as defined in IEEE 519-2014. If the system cannot meet the harmonic levels, the VFD must be provided with the manufacturer’s recommended line reactors or other isolation devices.

**2.3.8 Construction:**

The Drive must incorporate the following components and capabilities:

1. Input circuit breaker per UL 489 with a minimum of 10,000 amps symmetrical interrupting capacity.
2. Integral 3 percent or greater impedance line reactors to reduce the harmonics to the power line and to add protection from AC line transients. Drive must comply with IEEE standard 519.
3. Surge protection meeting IEEE C62.41.2 to protect the unit from damaging transient voltage surges. Surge arrestor must be mounted near the incoming power source and properly wired to all three phases and ground. Fuses must not be used for surge protection.
4. A NEMA 1 rated enclosure in accordance with NEMA 250, NEMA ICS 7, NEMA ICS 6 standards where the standards must override the enclosure rating and is the contractor’s responsibility to meet the standard. The enclosure must utilize an integral disconnect device. A mechanical interlock must prevent an operator from opening the AC Drive door while the disconnect is in the ON position. Another mechanical interlock must prevent an operator from placing the disconnect in the ON position while the AC Drive door is open. It must be possible for authorized personnel to defeat these interlocks. The door must have hardware to allow it to be locked with a padlock.
5. Bypass with selector switch along with properly sized IEC or NEMA rated manual by-pass and isolation contactors, with mechanical and electrical interlocks, to enable operation of the motor in the event of VFD failure. Bypass must not require external control power for operation.
6. Solid state I2t protection that is UL listed and meets UL 508 C as a Class 10 and Class 20 overload protection. The minimum adjustment range must be from 45% to 105% of the current output of the VFD. The unit must contain a thermal relay providing motor overload and stall protection in the manual bypass mode.
7. External input/output contacts as specified and shown. The safety input must stop the fan. The fire alarm panel (FAP) input, allowing the fireman to start/run the fan, must have priority over all other inputs/commands to the drive. FAP input must have priority over Safety input.
8. The drive must incorporate protective circuitry to protect the drive against the following events:

* Short circuit, ground fault, or open circuit at drive output.
* Input undervoltage or overvoltage.
* Loss of input phase.
* AC line switching transients.
* Sustained overload exceeding 110 % (adjustable) of controller rated current.
* Over temperature.
* Subjecting the drive to any of the above events must not result in component failure nor require fuse replacement.

**2.3.9 Microprocessor based controller.**

The drive must incorporate a microprocessor based controller with the following capabilities:

1. Ability to control output frequency from either the Manual Controls, an external input, or from the network interface.
2. Ability to monitor drive and motor parameters and provide that data to the external interface, manual controls, or network interface as specified below.
3. Configuration and control of all drive parameters including external input/output contacts as shown.
4. Manual or Automatic operation.
5. Adjustment of the sustained current limit.
6. For a fault condition other than a ground fault, short circuit or internal fault, an auto restart function will provide up to 5 programmable restart attempts. The programmable time delay before restart attempts will range from 1 second to 600 seconds.

**2.3.10 Display and Manual Controls:**

1. The drive must provide an LCD display and manual controls on the front panel. These controls must provide the following capabilities:
2. A high-resolution display with LCD backlight screen capable of displaying graphics such as bar graphs as well as at least six lines of twenty-one alphanumeric characters.
3. Manual speed UP / DOWN adjustment.
4. Hand-Off-Auto (H-O-A) switch.
5. Power on indicator.
6. Display and adjustment of all drive parameters via a menu-driven interface.
7. Display of drive commands: Forward / Off / Reverse and speed setpoint. Display of motor run status (Forward / Off / Reverse), output frequency (Hertz and percent), and loss of load fault.
8. Display of average phase voltage (V), average phase current (Amps), and total power (kW) to the motor. Display of motor torque as percent of full load. Display of input voltage and DC bus voltage. Display total motor energy (kWhr) and ability to reset this value.
9. Display of drive status (Run status, H-O-A switch indicator, Fault (including Protective circuit), etc.). Drive status other than faults must be either a dedicated indicator or plain English on the LCD display. Drive fault status must be either a dedicated indicator or must be both an English language status and a specific error code on the LCD display.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

If the building has an existing networked DDC system and there is a desire to add the VFD to that system then the specification should include the communications network interface requirement.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

[**2.3.11 Communication Network Interface**

1. The VFD must be a (LonWorks) Application Specific Controller (ASC) as defined in Section 23 09 23.01 and must meet all requirements of an ASC or be a BACnet non-programmable controller as defined in Section 23 09 23.02 or be compatible with the pre-existing building control network. The selection must match the existing building control system (BCS) communications protocol, and be coordinated with the installation.
2. The interface must follow the standard BCS communication protocol. If LonWorks provide TP/FT-10 and provide nvi (network variable input) and nvo (network variable output) SNVTs (Standard Network Variable Types) or if BACnet provide MSTP and provide standard Object Type properties to report and control the following:

* Motor command (Forward / Off / Reverse) and output frequency
* Drive status including any fault or alarm indicators
* Remote reset of drive faults
* Total run time
* Line side volts, amps, power, and accumulated energy (kWhr)]

**2.4 Acceptable Products.**

Any product meeting the specified requirements may be provided.

**2.4.1 Instrumentation and Control Devices**

Unless otherwise specified, provide sensors and instrumentation that incorporate an integral transmitter. Sensors and instrumentation, including their transmitters, must meet the specified accuracy and drift requirements at the input of the connected DDC Hardware's analog-to-digital conversion.

**2.4.2 Analog and Binary Transmitters**

Provide transmitters which match the characteristics of the sensor. Transmitters providing analog values must produce a linear 4-20 mAdc, 0-10 Vdc signal corresponding to the required operating range and must have zero and span adjustment. Transmitters providing binary values must have dry contacts rated at 1A at 24 Volts AC.

**2.4.3 Network Transmitters**

Sensors and Instrumentation incorporating an integral network connection are considered DDC Hardware and must meet the DDC Hardware requirements of Section 23 09 23.01 LONWORKS DIRECT DIGITAL CONTROL FOR HVAC AND OTHER BUILDING CONTROL SYSTEMS when used in a LonWorks network, or the requirements of 23 09 23.02 BACNET DIRECT DIGITAL CONTROL FOR HVAC AND OTHER BUILDING CONTROL SYSTEMS when used in a BACnet network.

**2.4.4 Airflow Measurement Array (AFMA)**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Care should be taken in determining which technology is best suited for the application. While differential pressure measurement is usually the least expensive, it has poor accuracy at low air velocities below about 400-700 fpm. Outside influences (building pressure, wind gusts, etc.) can also impact accuracy due to potential fluctuations in air pressure. When sizing an AFMA for applications where the minimum OA and economizer functions are combined into one AFMA (and associated damper), a review of the conditions at the minimum OA flow is prudent to make sure the desired AFMA can accurately read at this design point.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Provide AFMAs that do not require an airflow straightener.

**2.4.4.1 Outside Air Temperature**

In outside air measurement or in low-temperature air delivery applications, provide an AFMA certified by the manufacturer to be accurate as specified over a temperature range of -20 to +120 degrees F.

**2.4.4.2 Pitot Tube AFMA**

Each Pitot Tube AFMA must contain an array of velocity sensing elements. The velocity sensing elements must be of the multiple pitot tube type with averaging manifolds. The sensing elements must be distributed across the duct cross section in the quantity and pattern specified or recommended by the published installation instructions of the AFMA manufacturer.

1. Pitot Tube AFMAs for use in airflows over 600 fpm must have an accuracy of plus or minus 5 percent over a range of 500 to 2500 fpm.
2. Pitot Tube AFMAs for use in airflows under 600 fpm must have an accuracy of plus or minus 5 percent over a range of 125 to 2500 fpm.

**2.4.4.3 Electronic AFMA**

Each electronic AFMA must consist of an array of velocity sensing elements of the resistance temperature detector (RTD) or thermistor type. The sensing elements must be distributed across the duct cross section in the quantity and pattern specified or recommended by the published application data of the AFMA manufacturer. Electronic AFMAs must have an accuracy of plus or minus 5 percent over a range of 125 to 5,000 fpm and the output must be temperature compensated over a range of 32 to 212 degrees F.

**2.4.4.4 Fan Inlet Measurement Devices**

Fan inlet measurement devices cannot be used unless indicated on the drawings or schedules.

**2.4.5 Space, Temperature, Occupancy, and CO2 Sensors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Indicate requirements for each space sensor module on the schedule entitled ‘Space Sensor Module (Thermostat) and Zone Sensor’ the schedule drawing. A Space Sensor Module may be commonly referred to as a thermostat but should not be confused with devices that have contact outputs for control of heating/cooling equipment (fans, compressors, etc.).

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**2.4.5.1 Space Sensor Module**

Space Sensor Modules, sometimes referred to as thermostats, must be multifunction devices incorporating a temperature sensor and one or more of the following as specified and indicated on the Space Sensor Module Schedule:

1. A temperature indicating device.
2. A User Input Device which must adjust a temperature setpoint output.
3. A User Input Momentary Contact Button and an output to the control system indicating zone occupancy.
4. A three position User Input Switch labeled to indicate heating, cooling, and off positions ('HEAT-COOL-OFF' switch) and providing corresponding outputs to the control system.
5. A two position User Input Switch labeled with 'AUTO' and 'ON' positions and providing corresponding output to the control system.
6. A multi-position User Input Switch with 'OFF' and at least two fan speed positions and providing corresponding outputs to the control system.
7. A relative humidity sensing device with a accuracy of plus or minus 3 percent, and not drift more than one percent per year.

**2.4.5.2 Temperature Sensor**

Provide the same sensor type for each temperature measuring usage throughout the project. Temperature sensors may be provided without transmitters. Where transmitters are used, the range must be the smallest available from the manufacturer and suitable for the application such that the range encompasses the expected range of temperatures to be measured. The end to end accuracy includes the combined effect of sensitivity, hysteresis, linearity and repeatability between the measured variable and the end user interface (graphic presentation) including transmitters if used.

**Sensor Accuracy and Stability of Control**

1. Conditioned Space Temperature

* Plus or minus 0.5 degree F over the operating range

1. Duct Temperature

* Plus or minus 0.5 degree F

1. Outside Air Temperature

* Plus or minus 2 degrees F over the range of -30 to +130 degrees F AND
* Plus or minus 1 degree F over the range of 30 to +130 degrees F

**Temperature Sensor Details**

1. Room Type

* Provide the sensing element components within a decorative protective cover suitable for surrounding decor.

1. Duct Probe Type

* Ensure the probe is long enough to properly sense the air stream temperature.

1. Duct Averaging Type

* Continuous averaging sensors must be one foot in length for each 1 square foot of duct cross-sectional area, and a minimum length of 5 feet.

1. Outside Air Type

* Provide the sensing element rated for outdoor use.

**2.5.4.3 Occupancy Sensors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Indicate the type of occupancy sensor required on the control system Schedules drawing in the ‘OTHER’ column of the ‘Zone Sensor Schedule’**.**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Occupancy sensors must have occupancy-sensing sensitivity adjustment and an adjustable off-delay timer with a setpoint of 15 minutes, adjustments accessible from the face of the unit are preferred. Occupancy sensors must be rated for operation in ambient air temperatures ranging from 40 to 95 degrees F or temperatures normally encountered in the installed location. Sensors integral to wall mount on-off light switches must have an auto-off switch. Wall switch sensors must be decorator style and must fit behind a standard decorator type wall plate. All occupancy sensors, power packs, and slave packs must be UL listed. In addition to any outputs required for lighting control, the occupancy sensor must provide an output for the HVAC control system.

1. Passive Infrared (PIR) Occupancy Sensors

PIR occupancy sensors must have a multi-level, multi-segmented viewing lens and a conical field of view with a viewing angle of 180 degrees and a detection of at least 6 m 20 feet unless otherwise indicated or specified. PIR Sensors must provide field-adjustable background light-level adjustment with an adjustment range suitable to the light level in the sensed area, room, or space. PIR sensors must be immune to false triggering from RFI and EMI.

1. Ultrasonic Occupancy Sensors

Ultrasonic sensors must operate at a minimum frequency 32 kHz and must be designed to not interfere with hearing aids.

1. Dual-Technology Occupancy Sensor (PIR and Ultrasonic)

Dual-Technology Occupancy Sensors must meet the requirements of both PIR and Ultrasonic Occupancy Sensors.

* + - 1. **Carbon Dioxide (CO2) Sensors**

Provide photometric type CO2 sensors with integral transducers and linear output. Carbon dioxide (CO2) sensors must measure CO2 concentrations between 0 to 2000 parts per million (ppm) using non-dispersive infrared (NDIR) technology with an accuracy of plus or minus 50 ppm and a maximum response time of 1 minute. The sensor must be rated for operation at ambient air temperatures within the range of 32 to 122 degrees F and relative humidity within the range of 20 to 95 percent (non-condensing). The sensor must have a maximum drift of 2 percent per year. The sensor chamber must be manufactured with a non-corrosive material that does not affect carbon dioxide sample concentration. Duct mounted sensors must be provided with a duct probe designed to protect the sensing element from dust accumulation and mechanical damage. The sensor must have a calibration interval no less than 5 years.

**2.5.5 Actuators**

Actuators must be electric (electronic) or pneumatic to match the application and must be normally open (NO), normally closed (NC) or fail-in-last-position (FILP) as indicated. Normally open and normally closed actuators must be of mechanical spring return type. Electric actuators must have an electronic cut off or other means to provide burnout protection if stalled. Actuators must have a visible position indicator. Electric actuators must have a full stroke response time in both directions of 90 seconds or less. Electric actuators must be of the foot-mounted type with an oil-immersed gear train or the direct-coupled type. Where multiple electric actuators operate from a common signal, the actuators must provide an output signal identical to its input signal to the additional devices.

Damper actuators must provide the torque necessary per damper manufacturer's instructions to modulate the dampers smoothly over its full range of operation and torque must be at least 6 inch-pounds/1 square foot of damper area for opposed blade dampers and 9 inch-pounds/1 square foot of damper area for parallel blade dampers.

**Part 3 – Execution**

**3.1 Project Schedule**

Prepare a Project Schedule listing each submittal and prominent activity along with the due date of each. Activities must include but are not limited to Performance Verification Test (PVT) and Training. Submit [4] [\_\_\_\_\_] copies of the Project Schedule.

**3.2 Drawings**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

Template control system drawings are available for contract package use.

Many requirements refer to the Points Schedules drawing(s), especially setpoints and settings so it is critical that complete Points Schedules are part of the Contract Drawings.

Select a drawing size or to leave it up to the contractor.

Select an electronic submittal format in coordination with the project site. Be sure to require drawings in a format that is usable by the site maintenance staff. This may require including multiple format requirements here. Indicate drawing quantities.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**3.2.1 General**

When packaging drawings, group schedules by system and provide identifying titles/captions. When space allows, it is permissible to include multiple schedules for the same system on a single sheet. Except for drawings covering all systems, do not put information for different systems on the same sheet.

With each drawing set, provide a drawing Index showing the name and number of the building, military site, State or other similar designation, and Country. In the Drawing Index, list all drawings, including the drawing number, sheet number, drawing title, and computer filename when used. Provide a drawing legend showing and describing all symbols, abbreviations and acronyms used on the drawings. For multiple systems, provide a single index and legend for the entire drawing package.

**3.2.2 Points Schedules**

Provide a Points Schedule in tabular form for each HVAC system, with the indicated columns and with each row representing a hardware point, network point or configuration point in the system.

1. When a Points Schedule was included in the Contract Drawing package, use the same fields as the Contract Drawing with updated information in addition to the indicated fields. The specifier’s original Points Schedule spreadsheet may be available from the government’s quality assurance representative (QAR).
2. When Point Schedules are included in the contract package, items requiring contractor verification or input have been shown in angle brackets ("<" and ">"), such as <\_\_\_> for a required entry or <value> for a value requiring confirmation. Complete all items in brackets as well as any blank cells. Do not modify values which are not in brackets without approval. Refer to UFC 3-410-02 Appendix D for guidance on column entries.

**3.2.2.1 Points Schedule Definitions**

1. Point Name. The abbreviated name for the point using the indicated naming convention.
2. Description. A brief functional description of the point such as "Supply Air Temperature".
3. DDC Hardware Identifier. The Unique DDC Hardware Identifier shown on the DDC Hardware Schedule and used across all drawings for the DDC Hardware containing the point.
4. Settings. The value and units of any setpoints, configured setpoints, configuration parameters, and settings related to each point.
5. Range. The range of values, including units, associated with the point, including but not limited to a zone temperature setpoint adjustment range, a sensor measurement range, occupancy values for an occupancy input, or the status of a safety.
6. Input or Output (I/O) Type. The type of input or output signal associated with the point. Use the following abbreviations for entries in this column:

* AI: The value comes from a hardware (physical) Analog Input
* AO: The value is output as a hardware (physical) Analog Output
* BI: The value comes from a hardware (physical) Binary Input
* BO: The value is output as a hardware (physical) Binary Output
* PULSE: The value comes from a hardware (physical) Pulse Accumulator Input
* NET-IN: The value is provided from the network (generally from another device) Use this entry only when the value is received from another device as part of scheduling or as part of a sequence of operation, not when the value is received on the network for supervisory functions such as trending, alarming, override or display at a user interface.
* NET-OUT: The value is provided to another controller over the network. Use this entry only when the value is transmitted to another device as part of scheduling or as part of a sequence of operation, not when the value is transmitted on the network for supervisory functions such as trending, alarming, override or display at a user interface.

1. Object and Property Information. The Object Type and Instance Number for the Object associated with the point. If the value of the point is not in the Present\_Value Property, then also provide the Property ID for the Property containing the value of the point. Any point that is displayed at the front end or on an LDP, is trended, is used by another device on the network, or has an alarm condition must be documented here.
2. Primary Point Information: SNVT Name. The name of the SNVT used for the point. Any point that is displayed at the front end or on an LDP, is trended, is used by another device on the network, or has an alarm condition must be documented here.
3. Primary Point Information: SNVT Type. The SNVT type used by the point. Provide this information whenever SNVT Name is required.
4. Niagara Station ID. The Niagara Station ID of the Niagara Framework Supervisory Gateway the point is mapped into.
5. Network Data Exchange Information (Gets Data From, Sends Data To)
6. Provide the DDC Hardware Identifier of other DDC Hardware the point is shared with.
7. Override Information (Object Type and Instance Number). For each point requiring an Override and not residing in a Niagara Framework Supervisory Gateway, indicate if the Object for the point is Commandable or, if the use of a separate Object was specifically approved by the Contracting Officer, provide the Object Type and Instance Number of the Object to be used in overriding the point.
8. Override Information (SNVT Name and Type). For each point requiring an Override and not residing in a Niagara Framework Supervisory Gateway, indicate the SNVT Name and SNVT Type of the network variable used for the override.
9. Trend Object Information. For each point requiring a trend, indicate if the trend is Local or Remote, the trend Object type and the trend Object instance number. For remote trends provide the DDC Hardware Identifier for the device containing the trend Object in the Points Schedule notes.
10. Alarm Information. Indicate the Alarm Generation Type, Event Enrollment Object Instance Number, and Notification Class Object Instance Number for each point requiring an alarm. (Note that not all alarms will have Event Enrollment Objects.) Class Object Instance Number for each point requiring an alarm. (Note that not all alarms will have a Notification Class Object.)
11. Configuration Information. Indicate the means of configuration associated with each point.

* For points in a Niagara Framework Supervisory Gateway, indicate the point within the Niagara Framework Supervisory Gateway used to configure the value. For other points:
  + For Operator Configurable Points indicate BACnet Object and Property information (Name, Type, Identifiers) containing the configurable value. Indicate whether the property is writable always, or only when Out\_Of\_Service is TRUE.
  + For Configurable Points indicate the BACnet Object and Property information as for Operator Configurable points, or identification of the configurable settings from within the engineering software for the device or identification of the hardware settings on the device.
  + Indicate "Plug-In" if the point is configurable via an LNS plug-in. Indicate "Niagara Framework Wizard" if the point is configurable via a Niagara Framework Wizard. If the point is not configurable through an LNS plug-in Niagara Framework Wizard, indicate the network variable or configuration property used to configure the value.

**3.2.3 Submittals**

Drawings must be on [ISO A1 841x594 mm 34x22 inches] [or] [A3 420x297 mm 17x11 inches] sheets, and electronic drawings in PDF and in [AutoCAD] [Microstation] [Bentley BIM V8] [Autodesk Revit 2013] format. In addition, submit electronic drawings in editable Excel format for all drawings that are tabular, including but not limited to the Points Schedule.

1. DDC Contractor Design Drawings must consist of each drawing indicated with pre-construction information depicting the intended control system design and plans. Submit DDC Contractor Design Drawings 14 days prior to start of construction as a single complete package: [\_\_\_\_\_] hard copies and [\_\_\_\_\_] copies on CD-ROM.
2. Draft As-Built Drawings must consist of each drawing indicated updated with as-built data for the system prior to PVT. Submit Draft As-Built Drawings [7] [\_\_\_] days after acceptance of Start Up Test Report as a single complete package: [\_\_\_\_\_] hard copies and [\_\_\_\_\_] copies on CD-ROM.
3. Final As-Built Drawings must consist of each drawing indicated updated with all final as-built data. Final As-Built Drawings [7] [\_\_\_] days after acceptance of PVT Report as a single complete package: [\_\_\_\_\_] hard copies and [\_\_\_\_\_] copies on CD-ROM.

**3.3 Motors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Make appropriate motor selections based on replacement or reuse and indicate/list the fan motor(s) to be reused. Consider explicitly listing which motors are to be replaced and which are to be reused.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

[Install Motors in accordance with manufacturer’s published instructions, wiring diagrams and as indicated on project drawings.] [Reuse the existing supply fan motor [and return fan motor].] Ensure that motor pulleys are in line with fan pulleys and that belts are installed to manufacturer’s recommended tension. Re-use or replace all fan belt guards.

**3.4 Variable Frequency Drives**

Per NEMA ICS 3.1, install equipment in accordance with the approved manufacturer's printed installation drawings, instructions, wiring diagrams, and as indicated on project drawings and the approved shop drawings. Locate the VFD within 50 feet of the motor. Demonstrate proper fan rotation direction when the VFD is operating and when the VFD is bypassed.

**3.4.1 Start-Up**

Provide certified factory-authorized start-up service for installation inspection, initial drive equipment setting, energizing, and adjustment.

Total harmonic distortion must be calculated under worst case conditions in accordance with the procedure outlined in IEEE 519-1992. Copies of these calculations are to be made available upon request. The contractor must provide any needed information to the VFD supplier three (3) weeks prior to requiring harmonic calculations.

**3.4.2 Training**

Provide on-site training of owner’s representatives consisting of a ½ day trip to the jobsite in addition to the start-up service. Training must be conducted by a manufacturer’s qualified representative and consist of the following: Review of the Operation & Maintenance Manual, Instruction on proper operation of the equipment, Instruction on proper maintenance of the equipment.

**3.4.3 Submittals**

Submit Start-up form completed by a factory authorized installer for each drive as part of the project Start-Up and Start-Up Test Report.

**3.5 Instrumentation and Control Devices**

All devices must be installed in accordance with manufacturer's recommendations and as specified and indicated. Control devices to be installed in piping and ductwork must be provided with required gaskets, flanges, thermal compounds, insulation, piping, fittings, and manual valves for shutoff, equalization, purging, and calibration. Strap-on temperature sensing elements must not be used except as specified. Spare thermowells must be installed adjacent to each thermowell containing a sensor and as indicated.

**3.5.1 Air Flow Measurement Arrays (AFMA)**

Install AFMAs in accordance with the manufacturer's recommendations including minimum distances between upstream and downstream disturbances. Airflow straighteners may be used to reduce minimum distances as recommended by the AFMA manufacturer.

**3.5.2 Occupancy Sensors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** This section is included in case occupancy sensors are used in the project. Designer can delete if not required.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. Provide a sufficient quantity of occupancy sensors to provide complete coverage of the area (room or space). Occupancy sensors are to be ceiling mounted. Install occupancy sensors in accordance with NFPA 70 requirements and the manufacturer's instructions.
2. Do not locate occupancy sensors within 6 feet of HVAC outlets or heating ducts, or where they can "see" beyond any doorway. Installation above doorway(s) is preferred.
3. Do not use ultrasonic sensors in spaces containing ceiling fans.
4. Install sensors to detect motion to within 2 feet of all room entrances and to not trigger due to motion outside the room. Set the off-delay timer to 15 minutes unless otherwise indicated.
5. Adjust sensors prior to beneficial occupancy, but after installation of furniture systems, shelving, partitions, etc.
6. For each controlled area, provide one hundred percent coverage capable of detecting small hand-motion movements, accommodating all occupancy habits of single or multiple occupants at any location within the controlled room.

**3.5.3 Temperature Limit Switch**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** This section is included in case a temperature limit switch are used in the project. Designer can delete if not required.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. Provide a temperature limit switch (freezestat) to sense the temperature at the location indicated.
2. Provide a sufficient number of temperature limit switches to provide complete coverage of the duct section but no less than 1 foot in length per square meter square foot of cross-sectional area.
3. Install manual reset limit switches in approved, accessible locations where they can be reset easily.
4. Install temperature limit switch sensing elements in a side-to-side (not top-to-bottom) serpentine pattern with the relay section at the highest point and in accordance with the manufacturer's installation instructions.]

**3.5.4 Hand-Off Auto Switches**

Wire safety controls such as smoke detectors and freeze protection thermostats to protect the equipment during both hand and auto operation.

**3.5.5 Temperature Sensors**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** This section is included in case temperature sensors are used in the project. Designer can delete if not required.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Install temperature sensors in locations that are accessible and provide a good representation of sensed media. Installations in dead spaces are not acceptable. Calibrate and install sensors according to manufacturer’s instructions. Select sensors only for intended application as designated or recommended by manufacturer.

**3.5.6 Space Sensor Modules**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

A space sensor module is sometimes referred to as a thermostat.

All facilities should follow ADA standards unless the building is for able-bodied military personnel with no handicapped visitors, therefore select 48 inch mounting height unless otherwise approved.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Mount space sensor modules on interior walls and to sense the average room temperature. Avoid locations near heat sources such as copy machines or locations by supply air outlet drafts. Mount the center of all user-adjustable sensors 5 feet above the finished floor. Mount the center of all user-adjustable sensors [60][48] inches above the finished floor unless otherwise indicated. Mount adjustable devices to be ADA compliant unless otherwise indicated on the Space Sensor Schedule.

**3.5.7 Duct Temperature Sensors**

**3.5.7.1 Probe Type**

Place tip of the sensor in the middle of the airstream or in accordance with manufacturer's recommendations or instructions. Provide a gasket between the sensor housing and the duct wall. Seal the duct penetration airtight. When installed in insulated duct, provide enclosure or stand-off fitting to accommodate the thickness of duct insulation to allow for maintenance or replacement of the sensor and wiring terminations. Seal the duct insulation penetration vapor tight.

**3.5.7.2 Averaging Type**

Weave the sensing element in a serpentine fashion from side to side perpendicular to the flow, across the duct or air handler cross-section, using durable non-metal supports in accordance with manufacturer's installation instructions. Avoid tight radius bends or kinking of the sensing element. Prevent contact between the sensing element and the duct or air handler internals. Provide a duct access door at the sensor location. The access door must be hinged on the side, factory insulated, have cam type locks, and be as large as the duct will permit, maximum 18 by 18 inches. For sensors inside air handlers, the sensors must be fully accessible through the air handler's access doors without removing any of the air handler's internals.

**3.5.8 Damper Actuators**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** This section is included in case damper actuators are installed as a part of the project. Designer can delete if not required.

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Provide spring return actuators that fail to a position that protects the served equipment and space on all control dampers related to freeze protection or force protection. For all outside, makeup and relief dampers provide dampers that fail closed. Install actuators so that they move the blades smoothly throughout the full range of motion.

**3.6 Tags and Labels**

Match labels and tags to the unique identifiers indicated on the As-Built drawings. Label all enclosures and instrumentation. Tag all sensors and actuators installed as part of the project in mechanical rooms. Tag airflow measurement arrays to show flow rate range for signal output range, duct size, and pitot tube AFMA flow coefficient.

Provide plastic or metal tags, mechanically attached directly to each device, or attached by a metal chain or wire. Labels exterior to protective enclosures must be engraved plastic and mechanically attached to the enclosure or instrumentation. Labels inside protective enclosures may be attached using adhesive but must not be handwritten.

**3.7 Start-Up**

**3.7.1 Start-up and Start-Up Testing**

Perform start-up activities and the following startup tests for each control system to ensure that the described control system components are installed and functioning per this specification; Adjust, calibrate, measure, program, configure, set the time schedules, perform system inspection, calibration accuracy check, actuator range check, and otherwise perform all necessary actions to ensure that the systems function as indicated and shown in the sequence of operation and other contract documents.

**3.7.2 System Inspection**

With the system in unoccupied mode and with fan hand-off-auto switches in the OFF position, verify that power and main air, as applicable, are available where required and that all output devices are in their failsafe and normal positions. Where the following operator interface devices exist as required by the specifications or contract documents inspect each local display panel (LDP), operator workstation, and client workstation(s) to verify that each displays the control inputs, outputs, settings, setpoints, ranges, and other parameters necessary to operate and maintain the control system, and as described in the sequence of operation, and as shown in the Points Schedule drawing.

**3.7.3 Calibration Accuracy Check**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

A calibration check of the AFMA can be expensive unless TAB is included in the project.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

Perform a two-point accuracy check of the calibration of each HVAC control system sensor [except AFMA] by comparing the value from the test instrument to the network value provided by the DDC Hardware. Use test instruments with accuracy at least twice as accurate as the specified sensor accuracy and with calibration traceable to National Institute of Standards and Technology standards. Check the first point in the bottom one-third of the sensor range, and the second in the top one-third of the sensor range, if possible. Verify that the sensing element-to-DDC readout accuracies at two points are within the specified product accuracy tolerances, and if not recalibrate or replace the device and repeat the calibration check.

**3.7.4 Actuator Range Check**

With the system running, apply a signal to each actuator through the DDC Hardware controller. Verify proper operation of the actuators and positioners for all actuated devices and record the signal levels for the extreme positions of each device. Vary the signal over its full range and verify that the actuators travel from zero stroke to full stroke within the signal range. Where applicable, verify that all sequenced actuators move from zero stroke to full stroke in the proper direction, and move the connected device in the proper direction from one extreme position to the other. For valve actuators and damper actuators, perform the actuator range check under normal system pressures.

**3.7.5 Start-Up Test Report**

Submit [4] [\_\_\_\_\_] copies of the Start-Up Test Report. The report must document the results of the tests performed and certify that the system is installed and functioning per this specification and is ready for the Performance Verification Test (PVT). Start-Up Test Report must include the VFD start-up form.

**3.8 PERFORMANCE VERIFICATION TEST (PVT)**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

Indicate the required number of copies for the PVT Plan and PVT Report. Be consistent with the number of copies of ‘Start-Up Test’ report above.

Indicate the duration of the endurance test.

Include the PVT Plan Template in the project contract documents. The template is part of the ‘Multizone to Variable Volume Commissioning Guide’ spreadsheet.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**3.8.1 PVT Plan**

Prepare a PVT plan including procedures that describe step-by-step, the actions and expected results that will demonstrate that the control system performs in accordance with the sequences of operation, and other contract documents.

If the government provides a PVT Plan template, which is intended to facilitate the contractor’s PVT efforts, the contractor PVT Plan must be based on the government-provided template, where the contractor edits the provided template to be equipment and project-specific. The government’s PVT Plan template spreadsheet may be available from the QAR.

As the final step in the PVT Plan, include a [one-week] [\_\_\_\_\_] Endurance Test as part of the PVT during which the system is operated continuously and trend all points shown as requiring a trend on the Points Schedule for the entire endurance test. List and briefly describe a representative sample of trend logs/graphs to inspect at the end of the endurance test. This will minimally include fan speed command, zone damper command, and outside air flow cfm.

Submit [4] [\_\_\_\_\_] copies of the PVT Plan plus an electronic version in Excel spreadsheet format.

**3.8.2 PVT Execution**

Demonstrate compliance of the control system with the contract documents. Using test plans and procedures approved by the Government, demonstrate all physical and functional requirements of the project. Show, step-by-step, the actions and results demonstrating that the control systems perform in accordance with the sequences of operation. Do not start the PVT until after receipt of written permission by the Government, based on Government approval of the PVT Plan and receipt of the Draft As-Builts and completion of balancing (if specified). UNLESS GOVERNMENT WITNESSING OF A TEST IS SPECIFICALLY WAIVED BY THE GOVERNMENT, PERFORM ALL TESTS WITH A GOVERNMENT WITNESS. Do not conduct tests during scheduled seasonal off periods of base heating and cooling systems. If the system experiences any failures during the endurance test portion of the PVT, repair the system repeat the endurance test portion of the PVT until the system operates continuously and without failure for the specified endurance test period.

**3.8.3 PVT Report**

Prepare and submit a PVT report documenting all tests performed during the PVT and their results. Include all tests in the PVT procedures and any additional tests performed during PVT. Document test failures and repairs conducted with the test results. Document Endurance Test results.

Submit [4][\_\_\_\_\_] copies of the PVT Report plus an electronic version in Excel spreadsheet format.

**3.9 Training**

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

Indicate the number of students and number of hours of training. Consider adding training requirements in coordination with the maintenance staff based on their needs and experience. Be prepared to provide a training classroom.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**3.9.1 Training Course Attendee List**

Prior to training, in coordination with the [Controls][HVAC][Electrical][ ] shop supervisor, develop a Training Course Attendee list showing the location and date of the training along with the name and organization/shop of each training course attendee.

**3.9.2 Training Course Requirements**

Conduct a training course for [\_\_\_\_\_] operating staff members designated by the Government in the maintenance and operation of the system, Training will be [8] [\_\_\_\_\_] hours at the project site within 30 days after successful completion of

the Performance Verification Test. Provide a set of training materials to each student at the beginning of training minimally consisting of an agenda/list of training topics and a set of as-built drawings. The government reserves the right make audio and video recordings of the training. During training;

1. Describe the layout and location of each type of equipment/device and the locations of each.
2. Step through the sequence of operation and demonstrate fan capacity control.
3. Describe preventive maintenance, troubleshooting, diagnostics, calibration, adjustment, and repair procedures.
4. **End of Section**

APPENDIX C – SEQUENCES OF OPERATION

C-1. SEQUENCE OF OPERATION – HOT DECK BYPASS MULTIZONE RETROFIT

**Designer/Specifier Note:** Complete bracketed [ ] selections.

This sequence of operation is for a controls retrofit to convert a multizone to variable volume.

Select the DDC communications protocol technology in coordination with the site including LonWorks ‘Network Variables’, BACnet ‘Objects’, or Niagara Framework. If a proprietary protocol is selected, the local Contracts office may require a sole source justification.

Edit as needed for a system with a return fan. Return fan control requires identification/selection of an OFFSET that typically requires the services of a test, adjust, and balance (TAB) contractor that must be specified separately.

THE CONTRACTOR MUST PROVIDE DDC HARDWARE AND SOFTWARE TO PERFORM THIS SEQUENCE OF OPERATION AND TO PROVIDE NETWORK INPUTS, OUTPUTS, AND ALARM POINTS AS SPECIFIED AND AS SHOWN ON THE POINTS SCHEDULE DRAWING. UNLESS OTHERWISE SPECIFIED, ALL MODULATING CONTROL MUST BE PROPORTIONAL-INTEGRAL (PI) CONTROL. THE CONTRACTOR IS RESPONSIBLE FOR PROPERLY TUNING EACH CONTROL LOOP. TUNING VALUES SHOWN ARE PROVIDED FOR INFORMATION ONLY.

1. HAND-OFF-AUTO SWITCHES: THE SUPPLY FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE SUPPLY FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE SUPPLY FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE SUPPLY FAN RUNS, SUBJECT TO THE SUPPLY FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE SUPPLY FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Delete section B on Return Fan Variable Frequency Drive if Return Fan is not a part of the scope.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. [HAND-OFF-AUTO SWITCHES: THE RETURN FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE RETURN FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE RETURN FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE RETURN FAN RUNS, SUBJECT TO THE RETURN FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE RETURN FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.]
5. OCCUPANCY SCHEDULE: DAYS AND TIMES ARE AS SHOWN.
6. OCCUPANCY MODES: THE SYSTEM ACCEPTS AN OCCUPANCY COMMAND AND OCCUPANCY OVERRIDE COMMAND FROM THE NETWORK AS [NETWORK VARIABLE OF TYPE SNVT OCCUPANCY][STANDARD ASHRAE 135 SCHEDULE OBJECT] AND OPERATES IN ONE OF THE FOLLOWING MODES:

OCCUPIED MODE

UNOCCUPIED MODE

WARM-UP / COOLDOWN MODE

1. “ENABLED LOOPS BY OCCUPANCY MODE" ARE AS SHOWN IN THE DRAWING SCHEDULE
2. IN UNOCCUPIED MODE, “ENABLED LOOPS BY OCCUPANCY MODE" SCHEDULE SHOWS WHICH LOOPS ARE ENABLED BASED ON DDC SOFTWARE LOGIC AND SPACE SENSOR MODULE (ZONE THERMOSTAT) ZN-T SIGNALS WHERE:

MAX (ZN-T) = MAXIMUM ZONE TEMPERATURE RECEIVED FROM ALL SPACE SENSOR MODULES (ZONE THERMOSTATS).

MIN (ZN-T) = MINIMUM ZONE TEMPERATURE COMPARED TO ALL ZONE TEMPERTURES SPACE SENSOR MODULES (ZONE THERMOSTATS)

ZN-T-HL = HIGH LIMIT SETTING ABOVE WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 80 DEGREES F.

ZN-T-LL = LOW LIMIT SETTING BELOW WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 60 DEGREES F.

1. UNOCCUPIED MODE OVERRIDE IS ACCOMPLISHED VIA:
2. OCCUPANT ACCESSIBLE PUSHBUTTON LOCATED AT EACH SPACE SENSOR MODULE (ZONE THERMOSTAT) AND AT OTHER DEVICES AS SHOWN. WHEN PRESSED, THE SYSTEM IS IN OCCUPIED MODE FOR DURATION AS SHOWN.
3. OCCUPANCY SENSOR
4. [A NIGHT STAT MONITORS BUILDING TEMPERATURE (BLDG-T). IF BLDG-T DROPS BELOW THE NIGHT STAT SETTING THE SYSTEM ENTERS NIGHT STAT MODE AND THE FAN(S) START, THE OA DAMPER IS CLOSED, AND ZONE TEMPERATURE CONTROL IS ENABLED. THE SYSTEM EXITS NIGHT STAT MODE WHEN BLDG-T RISES 5 DEGREES F ABOVE THE NIGHT STAT SETTING.]
5. PROOFS AND SAFETIES: THE FAN(S) AND ALL DDC HARDWARE CONTROL LOOPS ARE SUBJECT TO PROOFS AND SAFETIES. SAFETIES ARE DIRECT-HARDWIRE INTERLOCKED TO THE FAN START CIRCUIT(S). DDC HARDWARE MONITORS ALL PROOFS AND SAFETIES AND ACTIVATION OF ANY SAFETY RESULTS IN ALL CONTROL LOOPS BEING DISABLED AND THE AHU FAN(S) BEING COMMANDED OFF UNTIL RESET AT THE SAFETY AND DDC HARDWARE RESET (VIA DDC SOFTWARE LOGIC) VIA A LOCAL PUSH-BUTTON (RST-BUT). ACTIVATION OF THE TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL) RESULTS IN CLOSING THE OUTSIDE AIR DAMPER.
6. PROOFS:

i. SUPPLY FAN STATUS (PROOF) (SF-S)

ii. [RETURN FAN STATUS (PROOF) (RF-S)]

1. SAFETIES

i. TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL)

ii. RETURN AIR SMOKE (RA-SMK)

1. FAN CAPACITY CONTROL

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

A minimum fan speed that is too low can be harmful to a motor. The minimum fan speed of 50% assumes reuse of an older pre-existing motor and is a conservative setting. It can be lower depending on the motor but you should check with a specialist or electrical engineer. A replacement premium efficiency motor can handle speeds approximately as low as 25%.

If there is a return fan the control scheme assumes fan matching (speed matching) and will require TAB for proper setup. Ensure that TAB is specified.

Return fan control using a ‘flow matching’ control scheme is typically much more accurate but also more expensive due to the need for 2 AFMAs; one each in the supply and return ducts. If the designer/specifier chooses this scheme insert a sequence of control and update the control drawings and points schedule.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. DISABLED: WHEN THIS LOOP IS DISABLED THE FAN IS COMMANDED OFF.
2. ENABLED: FAN CAPACITY IS UNDER VARIABLE FREQUENCY DRIVE CONTROL AS SHOWN IN THE CONTROL LOGIC DI\AGRAM.
3. VARIABLE FAN SPEED: SOFT START (RAMP) THE SUPPLY FAN AND MODULATE THE SUPPLY FAN COMMAND (SF-C) BASED ON THE ZONE DAMPER COMMAND (ZN-D-C) FOR EACH ZONE AS COMPARED TO THE CONFIGURED DAMPER/VALVE SETPOINT (ZN-DVC-SP) OF 95%. THE PROCESS VARIABLE FOR THIS LOOP IS MAXIMUM ZONE DAMPER/VALVE COMMAND (ZN-DVC-EFF) DETERMINED AS FOLLOWS AND AS SHOWN IN THE CONTROL LOGIC DIAGRAM:
4. STEP 1: DETERMINE THE ZONE DAMPER COMMANDED TO BE MOST OPEN TO COOLING: ZN-D-MAX
5. STEP 2: DETERMINE THE ZONE HEATING VALVE COMMANDED TO BE MOST OPEN TO HEATING: ZN-V-MIN (GIVEN THE ASSUMPTION THAT THE ZONE VALVES ARE N.O.).
6. STEP 3: USE THE MOST OPEN DAMPER OR HEATING VALVE FROM STEP 1 AND STEP 2 AS THE PROCESS VARIABLE (ZN-DVC-EFF) FOR THE PI CONTROL LOOP.
7. SUPPLY FAN SPEED MUST NOT BE REDUCED BELOW THE CONFIGURED MINIMUM SUPPLY FAN SPEED (SF-C-MIN)
8. THE FOLLOWING VALUES MUST BE CONFIGURABLE AND ARE BE CONFIGURED WITH THE FOLLOWING DEFAULT VALUES:

ZONE DAMPER/VALVE COMMAND SETPOINT: 95%

SUPPLY FAN COMMAND MINIMUM SPEED: 50%

1. SUGGESTED STARTING VALUES FOR LOOP TUNING ARE:

P = 1 (%FAN SPEED / %DAMPER POSITION OR 100% THROTTLING RANGE)

I = 0.1 REPEATS/MINUTE (10 MINUTES PER REPEAT OR 600 SECONDS PER REPEAT)

1. [RETURN FAN CONTROL. THE RETURN FAN COMMAND (RF-C) IS IDENTICAL TO THE SF-C MINUS THE AMOUNT OF THE OFFSET TO ENSURE THAT OVER THE FULL RANGE OF SF SPEEDS THE DUCT STATIC PRESSURE IS ALWAYS POSITIVE AT THE INLET TO THE RELIEF DAMPER.]

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:** Select either ‘fixed flow setpoint’ or ‘demand controlled ventilation’ based on either occupancy sensors or CO2 sensors.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. OUTSIDE AIR (OA) FLOW CONTROL
2. DISABLED: WHEN THIS LOOP IS DISABLED THE OA DAMPER IS CLOSED.
3. ENABLED: WHEN THIS LOOP IS ENABLED THE OA DAMPER IS CONTROLLED BASED ON:
4. [FIXED FLOW SETPOINT: THE OA DAMPER MODULATES TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT THE FIXED OCCUPIED SETPOINT (OA-F-SP) SCHEDULED FLOW.]
5. [OCCUPACY SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE OCCUPANCY AS SENSED BY THE CEILING MOUNT OCCUPANCY SENSORS IN ROOMS/ZONES [ ] ACCORDING TO THE FOLLOWING SCHEDULE:

OCC SENSOR STATUS OA FLOW SETPOINT

NO ROOMS/ZONES OCCUPIED [ ] CFM

ANY ROOM/ZONE OCCUPIED [ ] CFM ]

1. [CO2 SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE MAXIMUM ZONE CO2 (MAX-ZONE-CO2) SENSED IN ANY AREA/SPACE SERVED BY THE AHU ACCORDING TO THE FOLLOWING OA-F-SP LINEAR RESET SCHEDULE:

MAX-ZONE-C02 OA FLOW SETPOINT

[ ] PPM [ ] CFM (LOWER LIMIT)

[ ] PPM [ ] CFM (UPPER LIMIT) ]

1. PRE-EMPTIVE FREEZE PROTECTION: WITH SUPPLY FAN RUNNING AND THE MIXED AIR TEMPERATURE MORE THAN 3 DEGREES F BELOW THE MIXED AIR TEMPERATURE LOW LIMIT SETPOINT (MA-T-LL-SP), MODULATE THE OA DAMPER CLOSED USING A RESET SCHEDULE SUCH THAT THE OA DAMPER IS FULLY CLOSED AT A MIXED AIR TEMPERATURE OF 8 DEGREES F BELOW MA-T-LL-SP.
2. WHENEVER THE OA DAMPER IS COMMANDED TO FULL OPEN, THE SUPPLY FAN COMMAND MINIMUM (SF-C-MIN) MUST NOT DROP BELOW THAT NEEDED TO MAINTAIN OA FLOW SETPOINT.
3. MIXED AIR TEMPERATURE CONTROL WITH ECONOMIZER:
4. WHEN DISABLED: ECONOMIZER IS OFF
5. WHEN ENABLED:
6. ECONOMIZER IS ON WHEN THE OUTSIDE AIR DRY BULB TEMPERATURE IS BETWEEN THE HIGH LIMIT (ECO-HL-SP) AND LOW LIMIT (ECO-LL-SP) SETPOINTS AS SHOWN, WITH A 2 DEGREE F DEADBAND.
7. ECONOMIZER IS OFF OTHERWISE
8. WHEN ECONOMIZER IS ON, MODULATE THE ECONOMIZER OUTSIDE AIR, RELIEF, AND RETURN AIR DAMPERS TO MAINTAIN THE MIXED AIR TEMPERATURE (MA-T) AT SETPOINT (MA-T-SP) AS SHOWN. DAMPER COMMAND MUST NOT DROP BELOW THAT REQUIRED TO MAINTAIN OUTSIDE AIR FLOW CONTROL.
9. COLD DECK TEMPERATURE CONTROL
10. WHEN DISABLED: THE COLD DECK CONTROL VALVE IS CLOSED.
11. WHEN ENABLED: THE COLD DECK CONTROL VALVE MODULATES TO MAINTAIN COLD DECK TEMPERATURE (CD-T) AT SETPOINT (CD-T-SP).

1. COLD DECK VALVE CONTROL IS ENABLED WHEN BOTH:
2. COMMANDED TO BE ENABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, AND
3. \*ANY\* ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT SETPOINT (ANY ZN-D-C > CLG-OO-HL-SP). THE COLD DECK VALVE CONTROL REMAINS ENABLED UNTIL ALL ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT SETPOINT (ALL ZN-D-C < CLG-OO-LL-SP).
4. COLD DECK VALVE CONTROL IS DISABLED WHEN EITHER:
5. COMMANDED TO BE DISABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, OR
6. \*ALL\* ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT (ALL ZN-D-C < CLG-OO-LL). THE COLD DECK VALVE CONTROL REMAINS DISABLED UNTIL ANY ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT (ANY ZN-D-C > CLG-OO-HL).
7. CLG-OO-LL-SP AND CLG-OO-HL-SP ARE OPERATOR CONFIGURABLE WITH THE FOLLOWING INITIAL VALUES:
8. CLG-OO-LL-SP: 5%
9. CLG-OO-HL-SP: 15%
10. ZONE TEMPERATURE CONTROL:
11. THE ZONE TEMPERATURE SETPOINT (ZN-T-SP) IS AT THE OCCUPANT-ADJUSTABLE SETPOINT VIA THE WALL-MOUNTED SPACE SENSOR MODULE (THERMOSTAT).
12. THE ZONE HEATING VALVE AND COLD DECK DAMPERS MODULATE TO MAINTAIN ZONE TEMPERATURE (ZN-T) AT SETPOINT (ZN-T-SP).
13. UPON A RISE IN ZN-T ABOVE ZN-T-SP, THE ZONE COLD DECK DAMPER MODULATES OPEN TO THE COOLING COIL AND MODULATES CLOSED TO THE BYPASS. THE ZONE HEATING VALVE REMAINS CLOSED.
14. UPON A FALL IN ZONE TEMPERATURE BELOW ZONE TEMPERATURE SETPOINT THE ZONE COLD DECK DAMPER IS CLOSED TO THE COOLING COIL AND IS OPEN TO THE BYPASS.
15. UPON A FURTHER FALL IN ZONE TEMPERATURE BELOW ZONE TEMPERATURE SETPOINT THE ZONE HEATING VALVE MODULATES OPEN.
16. THE ZONE HEATING VALVE AND COLD DECK DAMPERS ARE SEQUENCED SO THAT BOTH THE COLD DECK DAMPER AND ZONE HEATING VALVE DO NOT OPEN SIMULTANEOUSLY (UNLESS THE ZONE DEHUMDIFICATION MODE IS ENABLED – SEE BELOW).

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**Designer/Specifier Note:** Delete dehumidification control if it is not required.

1. [ZONE HUMIDITY CONTROL (DEHUMIDIFICATION ONLY):
2. THE ZONE RELATIVE HUMIDITY SETPOINT (ZN-RH-SP) WILL INITIALLY BE SET TO 70% AND BE OPERATOR CONFIGURABLE AND ADJUSTABLE WITH TIMED OVERRIDE.
3. THE DDC HARDWARE ENABLES THE COLD DECK ZONE DAMPER CONTROL AND HEATING VALVE CONTROL SIMULTANEOUSLY WHEN THE RESPECTIVE ZONE RELATIVE HUMIDITY [ZN-RH] IS ABOVE SETPOINT [ZN-RH-SP]. DURING DEHUMIDIFICATION MODE:
   * 1. THE COLD DECK ZONE DAMPER WILL OPEN 100% TO THE COOLING COIL AND THE ZONE HEATING VALVE WILL MODULATE TO MAINTAIN ZONE TEMPERATURE (ZN-T) AT SETPOINT (ZN-T-SP).
4. THE DDC HARDWARE WILL DISCONTINUE DEHUMIDIFICATION MODE WHEN ZONE RELATIVE HUMIDITY (ZN-RH) FALLS BELOW ZONE RELATIVE HUMIDITY SETPOINT (ZN-RH-SP) MINUS A 5% (OPERATOR CONFIGURABLE) DEADBAND. WHEN DEHUMIDIFICATION MODE IS DISABLED, THE COLD DECK DAMPER AND ZONE HEATING VALVE RETURN TO NORMAL CONTROL.]

C-2. SEQUENCE OF OPERATION - CONVENTIONAL HOT DECK / COLD DECK MULTIZONE RETROFIT

**Designer/Specifier Note:** Complete bracketed [ ] selections.

This sequence of operation is for a controls retrofit to convert a multizone to variable volume.

Select the DDC communications protocol technology in coordination with the site including LonWorks ‘Network Variables’, BACnet ‘Objects’, or Niagara Framework. If a proprietary protocol is selected, the local Contracts office may require a sole source justification.

Edit as needed for a system with a return fan. Return fan control requires identification/selection of an OFFSET that typically requires the services of a test, adjust, and balance (TAB) contractor that must be specified separately.

THE CONTRACTOR MUST PROVIDE DDC HARDWARE AND SOFTWARE TO PERFORM THIS SEQUENCE OF OPERATION AND TO PROVIDE NETWORK INPUTS, OUTPUTS, AND ALARM POINTS AS SPECIFIED AND AS SHOWN ON THE POINTS SCHEDULE DRAWING. UNLESS OTHERWISE SPECIFIED, ALL MODULATING CONTROL IS PROPORTIONAL-INTEGRAL (PI) CONTROL. THE CONTRACTOR IS RESPONSIBLE FOR PROPERLY TUNING EACH CONTROL LOOP. TUNING VALUES SHOWN ARE PROVIDED FOR INFORMATION ONLY.

1. HAND-OFF-AUTO SWITCHES: THE SUPPLY FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE SUPPLY FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE SUPPLY FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE SUPPLY FAN RUNS, SUBJECT TO THE SUPPLY FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE SUPPLY FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.

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**Designer/Specifier Note:** Delete section B on Return Fan Variable Frequency Drive if Return Fan is not a part of the scope.

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1. [HAND-OFF-AUTO SWITCHES: THE RETURN FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE RETURN FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE RETURN FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE RETURN FAN RUNS, SUBJECT TO THE RETURN FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE RETURN FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.]
5. OCCUPANCY SCHEDULE: DAYS AND TIMES ARE AS SHOWN.
6. OCCUPANCY MODES: THE SYSTEM ACCEPTS AN OCCUPANCY COMMAND AND OCCUPANCY OVERRIDE COMMAND FROM THE NETWORK AS [NETWORK VARIABLE OF TYPE SNVT OCCUPANCY][STANDARD ASHRAE 135 SCHEDULE OBJECT] AND OPERATES IN ONE OF THE FOLLOWING MODES:

OCCUPIED MODE

UNOCCUPIED MODE

WARM-UP / COOLDOWN MODE

1. “ENABLED LOOPS BY OCCUPANCY MODE" ARE AS SHOWN IN THE DRAWING SCHEDULE
2. IN UNOCCUPIED MODE, “ENABLED LOOPS BY OCCUPANCY MODE" SCHEDULE SHOWS WHICH LOOPS ARE ENABLED BASED ON DDC SOFTWARE LOGIC AND SPACE SENSOR MODULE (ZONE THERMOSTAT) ZN-T SIGNALS WHERE:

MAX (ZN-T) = MAXIMUM ZONE TEMPERATURE RECEIVED FROM ALL SPACE SENSOR MODULES (ZONE THERMOSTATS).

MIN (ZN-T) = MINIMUM ZONE TEMPERATURE COMPARED TO ALL ZONE TEMPERTURES SPACE SENSOR MODULES (ZONE THERMOSTATS)

ZN-T-HL = HIGH LIMIT SETTING ABOVE WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 80 DEGREES F.

ZN-T-LL = LOW LIMIT SETTING BELOW WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 60 DEGREES F.

1. UNOCCUPIED MODE OVERRIDE IS ACCOMPLISHED VIA:
2. OCCUPANT ACCESSIBLE PUSHBUTTON LOCATED AT EACH SPACE SENSOR MODULE (ZONE THERMOSTAT) AND AT OTHER DEVICES AS SHOWN. WHEN PRESSED, THE SYSTEM IS IN OCCUPIED MODE FOR DURATION AS SHOWN.
3. OCCUPANCY SENSOR
4. [A NIGHT STAT MONITORS BUILDING TEMPERATURE (BLDG-T). IF BLDG-T DROPS BELOW THE NIGHT STAT SETTING THE SYSTEM ENTERS NIGHT STAT MODE AND THE FAN(S) START, THE OA DAMPER IS CLOSED, AND ZONE TEMPERATURE CONTROL IS ENABLED. THE SYSTEM EXITS NIGHT STAT MODE WHEN BLDG-T RISES 5 DEGREES F ABOVE THE NIGHT STAT SETTING.]
5. PROOFS AND SAFETIES: THE FAN(S) AND ALL DDC HARDWARE CONTROL LOOPS ARE SUBJECT TO PROOFS AND SAFETIES. SAFETIES ARE DIRECT-HARDWIRE INTERLOCKED TO THE FAN START CIRCUIT(S). DDC HARDWARE MONITORS ALL PROOFS AND SAFETIES AND ACTIVATION OF ANY SAFETY RESULTS IN ALL CONTROL LOOPS BEING DISABLED AND THE AHU FAN(S) BEING COMMANDED OFF UNTIL RESET AT THE SAFETY AND DDC HARDWARE RESET (VIA DDC SOFTWARE LOGIC) VIA A LOCAL PUSH-BUTTON (RST-BUT). ACTIVATION OF THE TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL) RESULTS IN CLOSING THE OUTSIDE AIR DAMPER.
6. PROOFS:

i. SUPPLY FAN STATUS (PROOF) (SF-S)

ii. [RETURN FAN STATUS (PROOF) (RF-S)]

1. SAFETIES

i. TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL)

ii. RETURN AIR SMOKE (RA-SMK)

1. FAN CAPACITY CONTROL

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**Designer/Specifier Note:**

A minimum fan speed that is too low can be harmful to a motor. The minimum fan speed of 50% assumes reuse of an older pre-existing motor and is a conservative setting. It can be lower depending on the motor, but you should check with a specialist or electrical engineer. A replacement premium efficiency motor can handle speeds approximately as low as 25%.

If there is a return fan the control scheme assumes fan matching (speed matching) and will require TAB for proper setup. Ensure that TAB is specified.

Return fan control using a ‘flow matching’ control scheme is typically much more accurate but also more expensive due to the need for 2 AFMAs; one each in the supply and return ducts. If the designer/specifier chooses this scheme insert a sequence of control and update the control drawings and points schedule.

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1. DISABLED: WHEN THIS LOOP IS DISABLED THE FAN IS COMMANDED OFF.
2. ENABLED: FAN CAPACITY IS UNDER VARIABLE FREQUENCY DRIVE CONTROL AS SHOWN IN THE CONTROL LOGIC DIAGRAM.
3. VARIABLE FAN SPEED: SOFT START (RAMP) THE SUPPLY FAN AND MODULATE THE SUPPLY FAN COMMAND (SF-C) BASED ON THE ZONE DAMPER COMMAND (ZN-D-C) FOR EACH ZONE AS COMPARED TO THE CONFIGURED DAMPER POSITION SETPOINT (ZN-D-SP) OF 95%. THE PROCESS VARIABLE FOR THIS LOOP IS MAXIMUM ZONE DAMPER COMMAND (ZN-D-C-EFF) DETERMINED AS FOLLOWS AND AS SHOWN IN THE CONTROL LOGIC DIAGRAM:
4. STEP 1: DETERMINE THE ZONE DAMPER COMMANDED TO BE MOST OPEN TO COOLING: ZN-D-MAX
5. STEP 2: DETERMINE THE ZONE DAMPER COMMANDED TO BE MOST OPEN TO HEATING: ZN-D-MIN (GIVEN THE ASSUMPTION THAT THE ZONE HEATING DAMPERS ARE N.O.).
6. STEP 3: USE THE MOST OPEN DAMPER FROM STEP 1 AND STEP 2 AS THE PROCESS VARIABLE (ZN-D-C-EFF) FOR THE PI CONTROL LOOP.
7. SUPPLY FAN SPEED MUST NOT BE REDUCED BELOW THE CONFIGURED MINIMUM SUPPLY FAN SPEED (SF-C-MIN)
8. THE FOLLOWING VALUES ARE CONFIGURABLE AND ARE CONFIGURED WITH THE FOLLOWING DEFAULT VALUES:

DAMPER COMMAND SETPOINT: 95%

SUPPLY FAN COMMAND MINIMUM SPEED: 50%

1. SUGGESTED STARTING VALUES FOR LOOP TUNING ARE:

P = 1 (%FAN SPEED / %DAMPER POSITION OR 100% THROTTLING RANGE)

I = 0.1 REPEATS/MINUTE (10 MINUTES PER REPEAT OR 600 SECONDS PER REPEAT)

1. [RETURN FAN CONTROL. THE RETURN FAN COMMAND (RF-C) IS IDENTICAL TO THE SF-C MINUS THE AMOUNT OF THE OFFSET TO ENSURE THAT OVER THE FULL RANGE OF SF SPEEDS THE DUCT STATIC PRESSURE IS ALWAYS POSITIVE AT THE INLET TO THE RELIEF DAMPER.]
2. WHENEVER THE OA DAMPER IS COMMANDED TO FULL OPEN, THE SUPPLY FAN COMMAND MINIMUM (SF-C-MIN) MUST NOT DROP BELOW THAT NEEDED TO MAINTAIN OA FLOW SETPOINT.

**Designer/Specifier Note:** Select either ‘fixed flow setpoint’ or ‘demand controlled ventilation’ based on either occupancy sensors or CO2 sensors.

1. OUTSIDE AIR (OA) FLOW CONTROL
2. DISABLED: WHEN THIS LOOP IS DIABLED THE OA DAMPER IS CLOSED.
3. ENABLED: WHEN THIS LOOP IS ENABLED THE OA DAMPER IS CONTROLLED BASED ON:
4. [FIXED FLOW SETPOINT: MODULATE THE OA DAMPER TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT THE FIXED OCCUPIED SETPOINT (OA-F-SP) SCHEDULED FLOW.]
5. [OCCUPACY SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE OCCUPANCY AS SENSED BY THE CEILING MOUNT OCCUPANCY SENSORS IN ROOMS/ZONES [ ] ACCORDING TO THE FOLLOWING SCHEDULE:

OCC SENSOR STATUS OA FLOW SETPOINT

NO ROOMS/ZONES OCCUPIED [ ] CFM

ANY ROOM/ZONE OCCUPIED [ ] CFM ]

1. [CO2 SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE MAXIMUM ZONE C02 (MAX-ZONE-CO2) SENSED IN ANY AREA/SPACE SERVED BY THE AHU ACCORDING TO THE FOLLOWING OA-F-SP LINEAR RESET SCHEDULE:

MAX-ZONE-CO2 OA FLOW SETPOINT

[ ] PPM [ ] CFM (LOWER LIMIT)

[ ] PPM [ ] CFM (UPPER LIMIT) ]

1. PRE-EMPTIVE FREEZE PROTECTION: WITH SUPPLY FAN RUNNING AND THE MIXED AIR TEMPERATURE MORE THAN 3 DEGREES F BELOW THE MIXED AIR TEMPERATURE LOW LIMIT SETPOINT (MA-T-LL-SP), MODULATE THE OA DAMPER CLOSED USING A RESET SCHEDULE SUCH THAT THE OA DAMPER IS FULLY CLOSED AT A MIXED AIR TEMPERATURE OF 8 DEGREES F BELOW MA-T-LL-SP.
2. MIXED AIR TEMPERATURE CONTROL WITH ECONOMIZER:
3. WHEN DISABLED: ECONOMIZER IS OFF
4. WHEN ENABLED:
5. ECONOMIZER IS ON WHEN THE COLD DECK IS ENABLED AND THE OUTSIDE AIR DRY BULB TEMPERATURE IS BETWEEN THE HIGH LIMIT (ECO-HL-SP) AND LOW LIMIT (ECO-LL-SP) SETPOINTS AS SHOWN, WITH A 2 DEGREE F DEADBAND.
6. ECONOMIZER IS OFF OTHERWISE
7. WHEN ECONOMIZER IS ON, MODULATE THE ECONOMIZER OUTSIDE AIR, RELIEF, AND RETURN AIR DAMPERS TO MAINTAIN THE MIXED AIR TEMPERATURE (MA-T) AT SETPOINT (MA-T-SP) AS SHOWN. DAMPER COMMAND MUST NOT DROP BELOW THAT REQUIRED TO MAINTAIN OUTSIDE AIR FLOW CONTROL.
8. HOT DECK TEMPERATURE CONTROL:
9. WHEN DISABLED: THE HOT DECK CONTROL VALVE IS CLOSED.
10. WHEN ENABLED: THE HOT DECK CONTROL VALVE MODULATES TO MAINTAIN THE HOT DECK TEMPERATURE (HD-T) AT SETPOINT (HD-T-SP).
11. HOT DECK CONTROL VALVE IS ENABLED WHEN BOTH:
12. COMMANDED TO BE ENABLED ACCORDING TO THE 'ENABLED LOOPS BY OCCUPANCY MODE', AND
13. **ANY** ZONE DAMPER COMMAND IS LESS THAN THE HEATING ON/OFF LOW LIMIT (ANY ZN-D-C < HTG-OO-LL-SP) AND REMAINS ENABLED UNTIL ALL ZONE DAMPER COMMAND SIGNALS ARE GREATER THAN THE HEATING ON/OFF HIGH LIMIT (ALL ZN-D-C > HTG-OO-HL-SP).
14. HOT DECK CONTROL VALVE IS DISABLED WHEN EITHER:
15. COMMANDED TO BE DISABLED ACCORDING TO THE 'ENABLED LOOPS BY OCCUPANCY MODE', OR
16. **ALL** ZONE DAMPER COMMAND SIGNALS ARE GREATER THAN THE HEATING ON/OFF HIGH LIMIT (ALL ZN-D-C > HTG-OO-HL-SP) AND REMAINS DISABLED UNTIL ANY ZONE DAMPER COMMAND IS LESS THAN THE HEATING ON/OFF LOW LIMIT (ANY ZN-D-C < HTG-OO-LL-SP)
17. HTG-OO-LL-SP AND HTG-OO-HL ARE OPERATOR CONFIGURABLE WITH THE FOLLOWING INITIAL VALUES:

A. HTG-OO-LL-SP: 25%

B. HTG-OO-HL-SP: 65%

1. COLD DECK TEMPERATURE CONTROL
2. WHEN DISABLED: THE COLD DECK CONTROL VALVE IS CLOSED.
3. WHEN ENABLED: THE COLD DECK CONTROL VALVE MODULATES TO MAINTAIN COLD DECK TEMPERATURE (CD-T) AT SETPOINT (CD-T-SP).
4. COLD DECK VALVE CONTROL IS ENABLED WHEN BOTH:
5. COMMANDED TO BE ENABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, AND
6. \*ANY\* ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT (ANY ZN-D-C > CLG-OO-HL-SP) AND REMAINS ENABLED UNTIL ALL ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT (ALL ZN-D-C < CLG-OO-LL-SP).
7. COLD DECK VALVE CONTROL IS DISABLED WHEN EITHER:
8. COMMANDED TO BE DISABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, OR
9. \*ALL\* ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT (ALL ZN-D-C < CLG-OO-LL-SP) AND REMAINS DISABLED UNTIL ANY ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT (ANY ZN-D-C > CLG-OO-HL-SP).
10. CLG-OO-LL-SP AND CLG-OO-HL-SP ARE OPERATOR CONFIGURABLE WITH THE FOLLOWING INITIAL VALUES:
11. CLG-OO-LL-SP: 5%
12. CLG-OO-HL-SP: 15%
13. ZONE TEMPERATURE CONTROL:
14. THE ZONE TEMPERATURE SETPOINT (ZN-T-SP) IS AT THE OCCUPANT-ADJUSTABLE SETPOINT VIA THE WALL-MOUNTED SPACE SENSOR MODULE (THERMOSTAT).
15. THE DDC HARDWARE MODULATES THE HOT DECK AND COLD DECK DAMPERS IN UNISON TO MAINTAIN ZONE TEMPERATURE (ZN-T) AT SETPOINT (ZN-T-SP).
16. UPON A RISE IN ZN-T ABOVE ZN-T-SP, THE ZONE DAMPER MODULATES OPEN TO THE COLD DECK COOLING COIL AND CLOSED TO THE HOT DECK DAMPER HEATING COIL.
17. UPON A FALL IN ZONE TEMPERATURE BELOW ZONE TEMPERATURE SETPOINT THE HOT DECK DAMPER MODULATES OPEN TO THE HEATING COIL AND CLOSED TO THE COLD DECK COOLING COIL.

C-3. SEQUENCE OF OPERATION - NEUTRAL DECK MULTIZONE RETROFIT

**Designer/Specifier Note:** Complete bracketed [ ] selections.

This sequence of operation is for a controls retrofit to convert a multizone to variable volume.

Select the DDC communications protocol technology in coordination with the site including LonWorks ‘Network Variables’, BACnet ‘Objects’, or Niagara Framework. If a proprietary protocol is selected, the local Contracts office may require a sole source justification.

Edit as needed for a system with a return fan. Return fan control requires identification/selection of an OFFSET that typically requires the services of a test, adjust, and balance (TAB) contractor that must be specified separately.

THE CONTRACTOR MUST PROVIDE DDC HARDWARE AND SOFTWARE TO PERFORM THIS SEQUENCE OF OPERATION AND TO PROVIDE NETWORK INPUTS, OUTPUTS, AND ALARM POINTS AS SPECIFIED AND AS SHOWN ON THE POINTS SCHEDULE DRAWING. UNLESS OTHERWISE SPECIFIED, ALL MODULATING CONTROL IS PROPORTIONAL-INTEGRAL (PI) CONTROL. THE CONTRACTOR IS RESPONSIBLE FOR PROPERLY TUNING EACH CONTROL LOOP. TUNING VALUES SHOWN ARE PROVIDED FOR INFORMATION ONLY.

1. HAND-OFF-AUTO SWITCHES: THE SUPPLY FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE SUPPLY FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE SUPPLY FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE SUPPLY FAN RUNS, SUBJECT TO THE SUPPLY FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE SUPPLY FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.

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**Designer/Specifier Note:** Delete section B on Return Fan Variable Frequency Drive if Return Fan is not a part of the scope.

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1. [HAND-OFF-AUTO SWITCHES: THE RETURN FAN VARIABLE FREQUENCY DRIVE (VFD) MUST HAVE AN INTEGRAL H-O-A SWITCH:
2. HAND: WITH THE H-O-A SWITCH IN HAND POSITION, THE RETURN FAN STARTS AND RUNS CONTINUOUSLY, SUBJECT TO SAFETIES, AT A MANUALLY ADJUSTABLE SPEED.
3. OFF: WITH THE H-O-A SWITCH IN OFF POSITION, THE RETURN FAN STOPS.
4. AUTO: WITH THE H-O-A SWITCH IN AUTO POSITION, THE RETURN FAN RUNS, SUBJECT TO THE RETURN FAN START/STOP (SF-SS) COMMAND AND SAFETIES, ACCORDING TO THE RETURN FAN (SPEED) COMMAND (SF-C) AND THE FAN CAPACITY CONTROL LOOP.]
5. OCCUPANCY SCHEDULE: DAYS AND TIMES ARE AS SHOWN.
6. OCCUPANCY MODES: THE SYSTEM ACCEPTS AN OCCUPANCY COMMAND AND OCCUPANCY OVERRIDE COMMAND FROM THE NETWORK AS [NETWORK VARIABLE OF TYPE SNVT OCCUPANCY][STANDARD ASHRAE 135 SCHEDULE OBJECT] AND OPERATES IN ONE OF THE FOLLOWING MODES:

OCCUPIED MODE

UNOCCUPIED MODE

WARM-UP / COOLDOWN MODE

1. “ENABLED LOOPS BY OCCUPANCY MODE" ARE AS SHOWN IN THE DRAWING SCHEDULE
2. IN UNOCCUPIED MODE, “ENABLED LOOPS BY OCCUPANCY MODE" SCHEDULE SHOWS WHICH LOOPS ARE ENABLED BASED ON DDC SOFTWARE LOGIC AND SPACE SENSOR MODULE (ZONE THERMOSTAT) ZN-T SIGNALS WHERE:

MAX (ZN-T) = MAXIMUM ZONE TEMPERATURE RECEIVED FROM ALL SPACE SENSOR MODULES (ZONE THERMOSTATS).

MIN (ZN-T) = MINIMUM ZONE TEMPERATURE COMPARED TO ALL ZONE TEMPERTURES SPACE SENSOR MODULES (ZONE THERMOSTATS)

ZN-T-HL = HIGH LIMIT SETTING ABOVE WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 80 DEGREES F.

ZN-T-LL = LOW LIMIT SETTING BELOW WHICH THE MODE IS ACTIVE. USER ADJUSTABLE WITH DEFAULT = 60 DEGREES F.

1. UNOCCUPIED MODE OVERRIDE IS ACCOMPLISHED VIA:
2. OCCUPANT ACCESSIBLE PUSHBUTTON LOCATED AT EACH SPACE SENSOR MODULE (ZONE THERMOSTAT) AND AT OTHER DEVICES AS SHOWN. WHEN PRESSED, THE SYSTEM IS IN OCCUPIED MODE FOR DURATION AS SHOWN.
3. OCCUPANCY SENSOR
4. [A NIGHT STAT MONITORS BUILDING TEMPERATURE (BLDG-T). IF BLDG-T DROPS BELOW THE NIGHT STAT SETTING THE SYSTEM ENTERS NIGHT STAT MODE AND THE FAN(S) START, THE OA DAMPER IS CLOSED, AND ZONE TEMPERATURE CONTROL IS ENABLED. THE SYSTEM EXITS NIGHT STAT MODE WHEN BLDG-T RISES 5 DEGREES F ABOVE THE NIGHT STAT SETTING.]
5. PROOFS AND SAFETIES: THE FAN(S) AND ALL DDC HARDWARE CONTROL LOOPS ARE SUBJECT TO PROOFS AND SAFETIES. SAFETIES ARE DIRECT-HARDWIRE INTERLOCKED TO THE FAN START CIRCUIT(S). DDC HARDWARE MONITORS ALL PROOFS AND SAFETIES AND ACTIVATION OF ANY SAFETY RESULTS IN ALL CONTROL LOOPS BEING DISABLED AND THE AHU FAN(S) BEING COMMANDED OFF UNTIL RESET AT THE SAFETY AND DDC HARDWARE RESET (VIA DDC SOFTWARE LOGIC) VIA A LOCAL PUSH-BUTTON (RST-BUT). ACTIVATION OF THE TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL) RESULTS IN CLOSING THE OUTSIDE AIR DAMPER.
6. PROOFS:

i. SUPPLY FAN STATUS (PROOF) (SF-S)

ii. [RETURN FAN STATUS (PROOF) (RF-S)]

1. SAFETIES

i. TEMPERATURE LOW LIMIT (FREEZE STAT) (T-LL)

ii. RETURN AIR SMOKE (RA-SMK)

1. FAN CAPACITY CONTROL

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

**Designer/Specifier Note:**

A minimum fan speed that is too low can be harmful to a motor. The minimum fan speed of 50% assumes reuse of an older pre-existing motor and is a conservative setting. It can be lower depending on the motor but you should check with a specialist or electrical engineer. A replacement premium efficiency motor can handle speeds approximately as low as 25%.

If there is a return fan the control scheme assumes fan matching (speed matching) and will require TAB for proper setup. Ensure that TAB is specified.

Return fan control using a ‘flow matching’ control scheme is typically much more accurate but also more expensive due to the need for 2 AFMAs; one each in the supply and return ducts. If the designer/specifier chooses this scheme insert a sequence of control and update the control drawings and points schedule.

**\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\***

1. DISABLED: WHEN THIS LOOP IS DISABLED THE FAN IS COMMANDED OFF.
2. ENABLED: FAN CAPACITY IS UNDER VARIABLE FREQUENCY DRIVE CONTROL AS SHOWN IN THE CONTROL LOGIC DIAGRAM.
3. VARIABLE FAN SPEED: SOFT START (RAMP) THE SUPPLY FAN AND MODULATE THE SUPPLY FAN COMMAND (SF-C) BASED ON THE ZONE DAMPER COMMAND (ZN-D-C) FOR EACH ZONE AS COMPARED TO THE CONFIGURED DAMPER POSITION SETPOINT (ZN-D-SP) OF 95%. THE PROCESS VARIABLE FOR THIS LOOP IS MAXIMUM ZONE DAMPER COMMAND (ZN-D-C-EFF) DETERMINED AS FOLLOWS AND AS SHOWN IN THE CONTROL LOGIC DIAGRAM:
4. STEP 1: DETERMINE THE ZONE DAMPER COMMANDED TO BE MOST OPEN TO COOLING: ZN-D-MAX
5. STEP 2: DETERMINE THE ZONE DAMPER COMMANDED TO BE MOST OPEN TO HEATING: ZN-D-MIN (GIVEN THE ASSUMPTION THAT THE ZONE HEATING DAMPERS ARE N.O.).
6. STEP 3: USE THE MOST OPEN DAMPER FROM STEP 1 AND STEP 2 AS THE PROCESS VARIABLE (ZN-D-C-EFF) FOR THE PI CONTROL LOOP.
7. SUPPLY FAN SPEED MUST NOT BE REDUCED BELOW THE CONFIGURED MINIMUM SUPPLY FAN SPEED (SF-C-MIN)
8. THE FOLLOWING VALUES ARE CONFIGURABLE AND ARE CONFIGURED WITH THE FOLLOWING DEFAULT VALUES:

DAMPER COMMAND SETPOINT: 95%

SUPPLY FAN COMMAND MINIMUM SPEED: 50%

1. SUGGESTED STARTING VALUES FOR LOOP TUNING ARE:

P = 1 (%FAN SPEED / %DAMPER POSITION OR 100% THROTTLING RANGE)

I = 0.1 REPEATS/MINUTE (10 MINUTES PER REPEAT OR 600 SECONDS PER REPEAT)

1. [RETURN FAN CONTROL. THE RETURN FAN COMMAND (RF-C) IS IDENTICAL TO THE SF-C MINUS THE AMOUNT OF THE OFFSET TO ENSURE THAT OVER THE FULL RANGE OF SF SPEEDS THE DUCT STATIC PRESSURE IS ALWAYS POSITIVE AT THE INLET TO THE RELIEF DAMPER.]
2. WHENEVER THE OA DAMPER IS COMMANDED TO FULL OPEN, THE SUPPLY FAN COMMAND MINIMUM (SF-C-MIN) MUST NOT DROP BELOW THAT NEEDED TO MAINTAIN OA FLOW SETPOINT.

**Designer/Specifier Note:** Select either ‘fixed flow setpoint’ or ‘demand controlled ventilation’ based on either occupancy sensors or CO2 sensors.

1. OUTSIDE AIR (OA) FLOW CONTROL
2. DISABLED: WHEN THIS LOOP IS DIABLED THE OA DAMPER IS CLOSED.
3. ENABLED: WHEN THIS LOOP IS ENABLED THE OA DAMPER IS CONTROLLED BASED ON:
4. [FIXED FLOW SETPOINT: MODULATE THE OA DAMPER TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT THE FIXED OCCUPIED SETPOINT (OA-F-SP) SCHEDULED FLOW.]
5. [OCCUPACY SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN THE OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE OCCUPANCY AS SENSED BY THE CEILING MOUNT OCCUPANCY SENSORS IN ROOMS/ZONES [ ] ACCORDING TO THE FOLLOWING SCHEDULE:

OCC SENSOR STATUS OA FLOW SETPOINT

NO ROOMS/ZONES OCCUPIED [ ] CFM

ANY ROOM/ZONE OCCUPIED [ ] CFM ]

1. [CO2 SENSOR - DEMAND CONTROLLED VENTILATION: THE OUTSIDE AIR DAMPER MODULATES TO MAINTAIN OA VOLUMETRIC FLOW (OA-F) AT SETPOINT (OA-F-SP) BASED ON THE MAXIMUM ZONE C02 (MAX-ZONE-CO2) SENSED IN ANY AREA/SPACE SERVED BY THE AHU ACCORDING TO THE FOLLOWING OA-F-SP LINEAR RESET SCHEDULE:

MAX-ZONE-C02 OA FLOW SETPOINT

[ ] PPM [ ] CFM (LOWER LIMIT)

[ ] PPM [ ] CFM (UPPER LIMIT) ]

1. PRE-EMPTIVE FREEZE PROTECTION: WITH SUPPLY FAN RUNNING AND THE MIXED AIR TEMPERATURE MORE THAN 3 DEGREES F BELOW THE MIXED AIR TEMPERATURE LOW LIMIT SETPOINT (MA-T-LL-SP), MODULATE THE OA DAMPER CLOSED USING A RESET SCHEDULE SUCH THAT THE OA DAMPER IS FULLY CLOSED AT A MIXED AIR TEMPERATURE OF 8 DEGREES F BELOW MA-T-LL-SP.
2. MIXED AIR TEMPERATURE CONTROL WITH ECONOMIZER:
3. WHEN DISABLED: ECONOMIZER IS OFF
4. WHEN ENABLED:
5. ECONOMIZER IS ON WHEN THE COLD DECK IS ENABLED AND THE OUTSIDE AIR DRY BULB TEMPERATURE IS BETWEEN THE HIGH LIMIT (ECO-HL-SP) AND LOW LIMIT (ECO-LL-SP) SETPOINTS AS SHOWN, WITH A 2 DEGREE F DEADBAND.
6. ECONOMIZER IS OFF OTHERWISE
7. WHEN ECONOMIZER IS ON, MODULATE THE ECONOMIZER OUTSIDE AIR, RELIEF, AND RETURN AIR DAMPERS TO MAINTAIN THE MIXED AIR TEMPERATURE (MA-T) AT SETPOINT (MA-T-SP) AS SHOWN. DAMPER COMMAND MUST NOT DROP BELOW THAT REQUIRED TO MAINTAIN OUTSIDE AIR FLOW CONTROL.
8. HOT DECK TEMPERATURE CONTROL:
9. WHEN DISABLED: THE HOT DECK CONTROL VALVE IS CLOSED.
10. WHEN ENABLED: THE HOT DECK CONTROL VALVE MODULATES TO MAINTAIN THE HOT DECK TEMPERATURE (HD-T) AT SETPOINT (HD-T-SP).
11. HOT DECK CONTROL VALVE IS ENABLED WHEN BOTH:
12. COMMANDED TO BE ENABLED ACCORDING TO THE 'ENABLED LOOPS BY OCCUPANCY MODE', AND
13. **ANY** ZONE DAMPER COMMAND IS LESS THAN THE HEATING ON/OFF LOW LIMIT (ANY ZN-D-C < HTG-OO-LL-SP) AND REMAINS ENABLED UNTIL ALL ZONE DAMPER COMMAND SIGNALS ARE GREATER THAN THE HEATING ON/OFF HIGH LIMIT (ALL ZN-D-C > HTG-OO-HL-SP).
14. HOT DECK CONTROL VALVE IS DISABLED WHEN EITHER:
15. COMMANDED TO BE DISABLED ACCORDING TO THE 'ENABLED LOOPS BY OCCUPANCY MODE', OR
16. **ALL** ZONE DAMPER COMMAND SIGNALS ARE GREATER THAN THE HEATING ON/OFF HIGH LIMIT (ALL ZN-D-C > HTG-OO-HL-SP) AND REMAINS DISABLED UNTIL ANY ZONE DAMPER COMMAND IS LESS THAN THE HEATING ON/OFF LOW LIMIT (ANY ZN-D-C < HTG-OO-LL-SP)
17. HTG-OO-LL-SP AND HTG-OO-HL ARE OPERATOR CONFIGURABLE WITH THE FOLLOWING INITIAL VALUES:

A. HTG-OO-LL-SP: 25%

B. HTG-OO-HL-SP: 65%

1. COLD DECK TEMPERATURE CONTROL
2. WHEN DISABLED: THE COLD DECK CONTROL VALVE IS CLOSED.
3. WHEN ENABLED: THE COLD DECK CONTROL VALVE MODULATES TO MAINTAIN COLD DECK TEMPERATURE (CD-T) AT SETPOINT (CD-T-SP).
4. COLD DECK VALVE CONTROL IS ENABLED WHEN BOTH:
5. COMMANDED TO BE ENABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, AND
6. \*ANY\* ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT (ANY ZN-D-C > CLG-OO-HL-SP) AND REMAINS ENABLED UNTIL ALL ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT (ALL ZN-D-C < CLG-OO-LL-SP).
7. COLD DECK VALVE CONTROL IS DISABLED WHEN EITHER:
8. COMMANDED TO BE DISABLED ACCORDING TO THE ‘ENABLED LOOPS BY OCCUPANCY MODE’, OR
9. \*ALL\* ZONE DAMPER COMMAND SIGNALS ARE LESS THAN THE COOLING ON/OFF LOW LIMIT (ALL ZN-D-C < CLG-OO-LL-SP) AND REMAINS DISABLED UNTIL ANY ZONE DAMPER COMMAND IS GREATER THAN THE COOLING ON/OFF HIGH LIMIT (ANY ZN-D-C > CLG-OO-HL-SP).
10. CLG-OO-LL-SP AND CLG-OO-HL-SP ARE OPERATOR CONFIGURABLE WITH THE FOLLOWING INITIAL VALUES:
11. CLG-OO-LL-SP: 5%
12. CLG-OO-HL-SP: 15%
13. ZONE TEMPERATURE CONTROL:
14. THE ZONE TEMPERATURE SETPOINT (ZN-T-SP) IS AT THE OCCUPANT-ADJUSTABLE SETPOINT VIA THE WALL-MOUNTED SPACE SENSOR MODULE (THERMOSTAT).
15. THE DDC HARDWARE MODULATES THE HOT DECK, COLD DECK, NEUTRAL DECK DAMPERS TO MAINTAIN ZONE TEMPERATURE (ZN-T) AT SETPOINT (ZN-T-SP).
16. UPON A RISE IN ZN-T ABOVE ZN-T-SP, THE ZONE COLD DECK DAMPER MODULATES OPEN TO THE COOLING COIL AND CLOSED TO THE BYPASS. THE HOT DECK DAMPER MODULATES CLOSED TO THE HEATING COIL AND OPEN TO THE BYPASS.
17. UPON A FALL IN ZONE TEMPERATURE BELOW ZONE TEMPERATURE SETPOINT THE HOT DECK DAMPER MODULATES OPEN TO THE HEATING COIL AND CLOSED TO THE BYPASS. THE COLD DECK DAMPER MODULATES CLOSED TO THE COOLING COIL AND OPEN TO THE BYPASS.

APPENDIX D – MULTIZONE SCOPING GUIDE – AN OVERVIEW

A ‘Multizone to Variable Volume HVAC Controls Retrofit Scoping Guide’ spreadsheet tool is available for recording multizone ‘Preliminary Scoping’ and ‘Full Scoping’ information and data. This appendix provides an overview of the scoping activities.

**Preliminary Scoping**

Perform preliminary scoping to identify candidate multizone systems/units (across the entire installation) that merit further consideration and possible follow-up detailed field inspection. It is recommended that you team up with DPW / OMD (maintenance) staff, notably HVAC and Controls Technicians or similar staff members, to create a first pass list of units along with their basic characteristics.

Preliminary Scoping is likely to entail a brief visual inspection of each system/unit.

For each MZ system, provide an initial recommendation on whether to perform a subsequent field inspection. It is recommended that you select one or two strong candidates to start with, and work through the entire process before taking on all potential units. This allows you opportunity to tailor data collection to your site-specific needs.

‘Preliminary Scoping’ (categories):

* List identifying information for each MZ system/unit including;
  + Building name/number, unit identifier, location (e.g. mechanical room number)
* MZ type. (Conventional, Bypass, Neutral Deck). The ideal retrofit candidate is a Conventional multizone where the hot and cold decks are operated simultaneously. Other types are suitable but the ROI will likely not be as good.
* Variable Occupancy. Units that serve variable occupancy spaces are good candidates such as classrooms, conference rooms, assembly areas because they provide opportunity for reducing the outside airflow thus a reduced ventilation load and associated energy savings. The more variable occupancy spaces, the better.
* Unit age. If unknown, an approximation is useful where the intent is to help provide insight into the suitability of the unit for retrofit.
* Unit size. (Small, medium, large). Approximations are helpful for prioritizing units. Larger (fan and cfm) units will likely have sizable heating/cooling loads and provide opportunity for greater energy savings. For example:
  + Small: fan motor less than 5hp or less than 3000 cfm
  + Medium: fan motor 5-15 hp or 3000 - 10000 cfm
  + Large: fan motor more than 15hp or greater than 10,000 cfm
* Service life left. Units in reasonably good working order/condition or in a repairable condition are desirable. A reasonable return on investment will require that the system have at least 10 years of service life remaining, with the understanding that some repair/ refurbishment may be necessary and warranted. This is also discussed in Deal Breakers’ Section 5.1.
* Control system type. (DDC, analog electronic, or pneumatic). It would be useful to also note the general condition, especially the maintenance staff’s impression of the control system in regard to the benefit of replacing/upgrading it. Units with older, aging, or failed controls such as analog electronic or pneumatic controls may be good candidates because of the opportunity to upgrade them with more modern direct digital control (DDC) hardware. Pneumatic controls are a very old technology and prone to poor performance. Pneumatic control systems also often have older style mechanical timeclocks used to turn the system on/off on a schedule, where these clocks are prone to failure and/or disablement. With DDC, other system improvements become possible and the retrofit can provide connectivity with a supervisory monitoring and control system.
* Controls vendor. (Name/Brand). This can be helpful since the site may have experience with and thus a preference or bias for/against specific control system vendors/brands.
* LonWorks / BACnet / Other communications protocol. If known, indicate the existing control system open communications protocol technology. This can include Niagara Framework (also known as Tridium). Or, indicate if the existing control system uses a proprietary (non-open) communications protocol technology. This information can be helpful regarding he potential for connectivity of the system to a pre-existing supervisory system (e.g. a UMCS). This impacts the DDC specifications.
* Field inspection candidate? (yes, no, maybe). Provide an initial recommendation as to whether or not it would be beneficial to field inspect the unit. If ‘No’ this would suggest its ‘Priority’ (next category) is ‘low’. It may be premature to determine at this stage, but certain units may have ‘Deal Breaker’ aspects that suggest field inspection is not worthwhile. ‘Deal Breakers’ are described below.
* Priority (high, medium, or low). Take into account the above categories (primarily the unit type, size, variable occupancy, and service life) to assign a tentative/initial priority for follow-up investigation, in coordination with DPW / OMD (maintenance) staff recommendations.

**Full Scoping**

Use of the ‘Scoping Guide’ spreadsheet tool described in Section 5.2 is recommended for guiding and recording scoping information and data.

Full Scoping involves those units identified during ‘Preliminary Scoping’ as higher priority units and recommended for ‘Field Inspection’. As mentioned previously, it is recommended that you select one or two strong candidates to start with, and work through the entire process before taking on all potential units. This allows you opportunity to tailor data collection to your site-specific needs.

Full Scoping consists of assembling detailed information including available documentation about the candidate MZ systems/units along with performing a fairly detailed field inspection. Field inspection includes an assessment of the condition and functionality of system components. It should include identification of repair and refurbishment needs. Maintenance staff can be helpful with these activities.

Key ‘Scoping Guide’ items and activities to assess the condition of the MZ include:

* Availability and accuracy of as-built documentation.
* OA intake. Inspect to help determine if there is sufficient space for proper AFMA installation. Also refer to Section 6.2.
* Air distribution system. Inspect condition including condition of ductwork and duct insulation. Older ductwork is susceptible to air leaks. This includes damaged, split, or leaky duct seams and connections, deformed or flattened flex duct, flex duct separated/disconnected from diffusers, etc. Note needed repairs.
* AHU cabinets. Look for rust, condensate drain performance, door seals. Consider epoxy for repair/sealing for areas of corrosion.
* AHU and zone dampers and actuators. Check and tighten all crankarm linkages, jackshafts, and damper shafts. Verify that dampers fully close, especially the OA damper. Verify that actuators stroke over their full range of actuation.
* Zone balancing dampers. Note positions / settings. Verify that dampers are tight on their respective shafts. Note needed repairs.
* Fan motors and belts. Check for general condition and possible need for belt replacement. Fan motors inspection, including possible replacement, is described in detail in Section 6.6.
* Heating and cooling coils. Assess condition and identify the need for repair and/or coil surface cleaning.
* Valves and actuators. Look for external leakage. Verify that actuators stroke over their full range of actuation.

APPENDIX E – MULTIZONE CONTROLS RETROFIT ESTIMATOR – AN OVERVIEW

A ‘Multizone to Variable Volume HVAC Controls Retrofit Savings Estimator’spreadsheet tool is available to help perform an economic analysis of a MZ retrofit on multiple units. The estimator is designed to evaluate the energy and cost impact of implementing the retrofit and provide a payback analysis to assist in justifying the retrofit. It requires certain user provided inputs:

* Location
* Local Utility rates
* End Use Activity
* Unit Type (Conventional or Neutral Deck)
* Square footage (floor space) served
* Fan horsepower
* Heating and Cooling source

Estimated savings is based on experimental data from the technology demonstration, typical HVAC consumption by equipment type, end use, and location; and industry typical equipment efficiencies/costs. Additional user inputs, such as plans for demand control ventilation and presumed equipment efficiencies (e.g., for chiller, boiler), will allow for a more refined calculation and should be entered prior to contracting, but are not required for preliminary cost estimating.

In addition to the variable volume retrofit savings, the estimator will also provide energy savings and cost estimates for other improvements that might be conducted at the same time as the basic retrofit. Other energy savings measures include:

* Retro-commissioning (RCx)
* On/off scheduling
* Adding an economizer function to the AHU
* Conversion of pneumatic controls to DDC
* Replacing fan motors with premium efficiency motors.

APPENDIX F – Resilience Purchasing Justification

This variable volume controls retrofit of multizone air handlers improves energy resilience by reducing energy requirements by approximately 40%. Resilience benefits include decreased impact of potential threats to energy operations, increased adaptive capacity, and freed up operating capital.

Threats to energy operations, such as extreme weather, natural disasters, cyber or physical attack, and equipment failures, can result in disruptions to energy supply and energy services; requiring identification, acquisition, and allocation of alternate supplies (such as backup generators or secondary fuel types). These requirements are decreased by the more efficient retrofit systems, whose energy needs can be met with less alternate supply (e.g., fewer generators), reduced dependence on outside sources (fewer purchases of secondary fuel types), reduced demand on energy infrastructure (which leads to increased reliability), and greater flexibility to direct existing energy resources to priority assets to maintain key operations. The reduced dependence on outside energy sources can insulate against price volatility, resource availability bottlenecks, and potential resupply vulnerabilities. Additionally, decreased energy loads allow for increased passive survivability of facilities though extension of shelter-in-place activities. Furthermore, energy efficiency reduces environmental impacts and lifecycle costs, for long-term savings.

APPENDIX F – BIBLIOGRAPHY

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APPENDIX G - ABBREVIATIONS, ACRONYMS, DEFINITIONS

ADA American Disabilities Act

AFMA Air Flow Measurement Array

AHU Air Handling Unit

AI Analog Input

AO Analog Output

ASC Application Specific Controller

ASD Adjustable Speed Drive

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

BACnet A DDC communications protocol/technology

BCS Building Control System

BI Binary Input

BIM Building Information System

BLDG Building

BO Binary Output

BUT Button

Bypass 'Bypass Deck' A type of multizone system.

C Command

CC Cooling Coil

CD Cold Deck, Compact Disk

cfm cubic feet per minute

ChW Chilled Water

CLD Control Logic Diagrams

CLG Cooling

Conv 'Conventional'. A type of multizone system.

CO2 Carbon Dioxide

COP Coefficient of Performance

CV Constant Air Volume

D Damper

DCV Demand-Controlled Ventilation

DDC Direct Digital Control

DOE Department of Energy

DOI Digital Object identifier

DPS Differential Pressure Switch

DPW Directorate of Public Works

DVC Device

EA Exhaust Air or Relief Air

ECO Economizer

Eff Efficiency

EMI Electromagnetic Interference

ESTCP Environmental Security Technology Certification Program

F Fahrenheit, Flow

FACP Fire Alarm Control Panel

FAP Fire Alarm Panel

FAS Fire Alarm System

FILP Fail In Last Position

FPM Feet Per Minute

HC Heating Coil

HD Hot Deck

HL High Limit

H-O-A Hand-Off-Auto

HP Horsepower

HTG Heating

HVAC Heating, Ventilating, and Air Conditioning

HW Hot Water

ICS Industrial Control and Systems

ID Identification

IEC International Electrotechnical Commission

IEEE Institute of Electrical and Electronics Engineers

IN Input

ICS Industrial Control System

I/O Input/Output

ISO International Organization for Standardization

kW Killowatt

kWhr Kilowatt-hour

LCD Liquid Crystal Display

LDP Local Display Panel

LL Low Limit

LON LonWorks. A DDC communications protocol/technology.

LNS LonWorks Network Services

MA Mixed Air

mAdc Milli-Amps Direct Current

MAX Maximum

MG Motors and Generators

MIN Minimum

MM Millimeter

MSTP Master Slave Token Passing

MZ Multizone

NC Normally Closed

NDIR Non-dispersive infrared

NEMA National Electrical Manufacturers Association

Neutral 'Neutral Deck'. A type of multizone system.

NET Network

NFPA National Fire Protection Association

NG Natural Gas

NO Normally Open

NVI Network Variable Input

NVO Network Variable Output

O&M Operation and Maintenance

OA Outside Air

OCC Occupancy

OO On/Off

OMD Operations and Maintenance Division

OUT Output

P Position

PDF Portable Document Format

PI Proportional-Integral

PIR Passive Infrared

POS Position

PPM Parts Per Million

PVT Performance Verification Testing

PWS Performance Work Statement

PWM Pulse Width Modulation

QA Quality Assurance

QAR Quality Assurance Representative

RA Return Air

RCx Retrocommissioning

RFI Radio Frequency Interference

RLA Relief Air

RF Return Fan

RH Relative Humidity

RLA Relief Air

ROI Return on Investment

ROM Read Only Memory

RST Reset

RTD Resistance Temperature Detector

S Status

SD Submittal Description

SF Supply Fan

SMK Smoke

SNVTs Standard Network Variable Types

SP Set Point

SS Start/Stop

SSM Space Sensor Module

SSO Sequence of Operation

STAT Thermostat

T Thermostat or temperature

TAB Testing, Adjusting and Balancing

TP/FT Twisted Pair / Free Topology

UFC Unified Facilities Criteria

UFGS Unified Facilities Guide Specifications

UL Underwriters Laboratory

UMCS Utility Monitoring and Control System

WBDG Whole Building Design Guide

VFD Variable Frequency Drive

V Valve, Volts, Voltage

Vdc Voltage Direct Current

VV Variable Volume

ZN Zone

1. See the appendix and [www.wbdg.org/ffc/army-coe/design-guides](http://www.wbdg.org/ffc/army-coe/design-guides)/mz-vv-hvac-controls-retrofit for accompanying files. [↑](#footnote-ref-1)
2. See [www.wbdg.org/ffc/army-coe/design-guides](http://www.wbdg.org/ffc/army-coe/design-guides) for accompanying files [↑](#footnote-ref-2)
3. See [www.wbdg.org/ffc/army-coe/design-guides](http://www.wbdg.org/ffc/army-coe/design-guides) for accompanying files [↑](#footnote-ref-3)