AIRCUITY
Creating Measurably Better Environments

Aircuity Guide Specification

Rev. F090619

aircuity.com • info@aircuity.com

PART 1 GENERAL

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General Conditions of the Contract, General Conduct of the Work and Special Requirements, and Division 1 Specification Sections, apply to this Section.

1.2 OVERVIEW

A. This document contains the specification and input/output summaries for a Facility Monitoring System (FMS). The system architecture shall utilize local room, duct and outside air probes networked to distributed Air Data Routers and Sensors Suites communicating over a data and air sampling network. The air sampling network shall consist of an air packet transportation network that shall transport air samples from the environment being monitored to distributed Sensor Suites located throughout the facility. The air sampling network shall consist of intelligent air packet routers, an electrically conductive MicroDuct® network, Structured Cable and where applicable MD or OT Tubing. Gathering of air samples shall occur via room, wall, duct mounted, and outside air sampling probes located as indicated in the documents.

B. The FMS shall provide continuous monitoring of environmental conditions and ventilation performance as prescribed in the Sensor Suite section. With an active Aircuity Services Commitment the FMS shall provide protected information access via a web based user interface to analytical summaries, and in onscreen graphical form, system reports and analysis based notifications. Web-based utilities are to be included to export FMS data as a comma separated values (.csv) file format. The FMS shall interface with other analog and microprocessor based building subsystems as shown on the drawings, specified herein and in other sections.

C. The FMS specified herein, shall be by Aircuity, Inc., Newton Massachusetts. No other manufacturers are allowed.

[ALTERNATE PARAGRAPH TO BE INSERTED AFTER "THE FMS SPECIFIED HEREIN," NOTED IN PARAGRAPH 1.2 C. ABOVE IF FLAT SPECIFICATION OF EQUIPMENT IS FORBIDDEN] Alternate manufacturers may bid based upon meeting all requirements of the specification and receiving approval from the engineer 30 days prior to bid. A paragraph-by-paragraph comparison of the based bid specified system versus alternative system along with three references of similar projects (include project name, contact, phone number, location, consultant, value of contract, and a brief description of the control system and how it operates) shall be submitted prior to bid for review process. Bids shall not be accepted by Alternate manufacturer if approval is not received from the engineer prior to bid. If approved, other manufacturer's bids shall be shown as an add or deduct on the bid form.

1.3 RELATED SECTIONS

A. 3rd-Party Interfacing is required on this project according to the following Specification sections for sub-systems:

1. Section 230**XXX** – Building Automation System **[INSERT CORRECT SECTION # AND TITLE OF BUILDING AUTOMATION SYSTEM SPEC SECTION]**

B. REFERENCES

1. ANSI/ASHRAE 135-2016: BACnet® - A Data Communication Protocol for Building Automation Systems: This shall include the Standard and all published Addenda.

1.4 CODES, REGULATIONS, AND COMPLIANCE

1. All electrical equipment and material and its installation shall conform to the current requirements of the following authorities:

a) Occupational Safety and Health Act (OSHA)

b) National Electric Code (NEC)

c) National Fire Code

2. Where two or more codes conflict, the most restrictive shall apply. Nothing in this specification or related documentation shall be construed to permit work not conforming to applicable codes.
3. All Air Data Routers and Sensor Suites shall comply with:
   a) Underwriters Laboratories UL916 for Energy Management Equipment
   b) FCC Part 15 Class A
   c) CE
4. All Plenum Rated OSC Structured Cable shall comply with:
   a) UL CMP
   b) NEC 800.51 (A)
   c) NFPA 262
   d) UL 910
   e) FCC Part 15 Class A
   f) CE
5. All Riser Rated OSC Structured Cable shall comply with:
   a) UL CMR
   b) NEC 800.51 (B)
   c) ANSI 1666
   d) UL 1666
   e) FCC Part 15 Class A
   f) CE
6. All Plenum Rated MD MicroDuct shall comply with:
   a) NFPA 90A
   b) UL 94V-0
   c) UL 1820
   d) CE
7. All OT Tubing shall comply with:
   a) NFPA 90A
   b) UL 94V-2
   c) UL 1820
8. All Information Management Systems shall comply with:
   a) FCC Part 15 Class A
   b) CE
9. All Room and Duct Probes shall comply with:
   a) FCC Part 15 Class A
   b) CE
10. All Architectural Wall Probes shall comply with:
    a) UL94 HB
    b) CE

1.5 DEFINITIONS

A. **ADR** refers to the Aircuity Air Data Router

B. **AWP** refers to Aircuity's Architectural Wall probe

C. **BAS** refers to the Building Automation System. (Similar terms are: EMS, Energy Management System; BMS, Building Management System; FMS, Facility Management System; or ATC, Automatic Temperature Control.)

D. **DPB** refers to Aircuity's Duct Probe

E. **FMC** refers to the Facility Monitoring System Contractor. The FMC is the Contractor responsible for the implementation of this Section of the Specifications

F. **FMS** refers to the hardware, software and other components comprising the Facility Monitoring System as herein described

G. **I/O** refers to Input/Output. Thus, "I/O device" means "Input/Output device"

H. **IMS** refers to the Aircuity Information Management System

I. **LACS** refers to the Laboratory Airflow Control System

J. **MD** refers to the MD MicroDuct Tubing

K. **OT** refers to the OT Tubing

L. **OSC** refers to the OSC Structured Cable

M. **PCM** refers to a pump control module

N. **RS** refers to Aircuity's Room Probe

O. **SST** refers to the Aircuity Sensor Suite

1.6 ACCEPTABLE FACILITY MONITORING SYSTEM CONTRACTOR (FMC)

A. The FMC shall have support services within a **[XX]** mile radius of Project Site and comply with the service requirements of a **[XX]** hour response time. Any technicians working on the FMS will be certified by the FMS manufacturer for such work. Support services is defined as having access to complete parts inventory, having all required test and diagnostic equipment, and having factory certified technicians on the systems specified herein.

PART 2 PRODUCTS

2.1 CONTRACTOR RESPONSIBILITIES:

A. The FMC shall furnish all necessary hardware, wiring, Structured Cable, Tubing, computing equipment and software required to provide a complete and functional system necessary to perform the design intent and as defined in this specification.

B. Installation of all FMS components; and all electrical work required as an integral part of this section as noted in Part 3 Execution including but not limited to Sensor Suites, Air Data Routers, Room, Wall, Duct, and Outside Air Probes, Transformers, Vacuum Pumps, Information Management Systems, Structured Cable, MD Tubing, and where applicable OT Tubing, etc., shall be by **[INSERT DIVISION OR SECTION NUMBER OR NAME, CONTRACTOR NAME, TRADE GROUP, ETC., WHO WILL PERFORM THE FMS INSTALLATION.]**

C. The base price of the system will include a comprehensive Aircuity Services Commitment agreement for **[XX]** years as described in the Aircuity Services Commitment agreement portion of this specification.

2.2 CONTRACTOR (FMC) EXPERIENCE AND PERFORMANCE

A. The FMC shall have a local office or representative, staffed with factory certified technicians, fully capable of providing instruction, routine maintenance, and emergency maintenance service on all system components. The FMC shall be responsible for replacement of all products supplied at all times for a period of not less than 1 year following project completion, and shall provide a **[XX]** hour response to a service/warranty call from the owner.

2.3 SYSTEM REQUIREMENTS

A. All material and equipment used shall be standard components, regularly manufactured and available by the manufacturer and not custom designed especially for this project. All systems and components, except site specific software, shall have previously been thoroughly tested and proven in actual use prior to installation on this project.

B. The system shall have the ability to host multiple sensors for the purpose of simultaneously sensing multiple parameters from a single test area’s environment.

C. The system shall provide the end user the ability to select which environmental parameters will be sensed on a test area by test area basis.

D. The system shall have the ability to make true differential measurements by utilizing the same suite of sensors to evaluate both the contaminant levels of a test area and the source of the ventilation air.

E. The system shall have the ability to perform application specific computations using sensed contaminant levels for the purposes of generating ventilation command signals to be read by a BAS or LACS via hardwired outputs or BACnet over IP connections.

F. For the purposes of generating analytical data and reports based of off actual system performance, the FMS shall have the ability to take in third party feedback data by one or both of the following methods:

1. Feedback data is regularly written to the FMS by the BAS or LACS via hardwired inputs or BACnet over IP connections at regular intervals as specified in the integration appendices later in this document.

2. FMS obtains feedback data by actively querying for known, exposed feedback data values over the BACnet network at regular intervals as specified in the BACnet integration appendix found later in this document.

G. The system architecture shall be fully modular permitting expansion of application software, system peripherals, and field hardware.

H. The system, upon completion of the installation and prior to acceptance of the project, shall perform all operating functions as detailed in this specification.

2.4 EQUIPMENT

A. System Hardware

1. The FMC shall provide the following:

a) All Air Data Routers, Sensor Suites, Sensor Suite Sensors, Room, Wall, Duct, and Outside Air Probes, Information Management Systems, Vacuum Pumps, Structured Cable, MD Tubing, OT Tubing, and Transformers to perform the functions listed.

B. System Software

1. The FMC shall provide all software identified in this specification. The database required for implementation of these specifications shall be provided by the FMC, including point descriptors, test sequences, reports and point summaries. The FMC shall provide and create the system using the latest software release, at the time of Shop Drawing approval.

2. **[INCLUDE THIS SECTION ONLY IF THE PROJECT REQUIRES BACnet INTEGRATION. ALSO REFER TO APPENDIX B FOR SECTIONS THAT MUST BE ADDED TO THE BAS SPECIFICATION]**

The FMC shall provide a BACnet compatible integrated system and software to interface with the facility's BAS. Communication shall be via BACnet over IP.

[REFER TO APPENDIX C FOR SECTIONS THAT MUST BE ADDED TO THE BAS SPECIFICATION IF YOUR PROJECT WILL FEATURE HARDWIRED I/O (FEEDBACKS, DCV COMMAND SIGNALS, ETC.)]

C. Building Ethernet Connection Cabling:

1. The owner shall provide CAT-5e or CAT-6 network drops and cabling between the FMS Information Management System and:

a) The owner's Building Ethernet Network - to serve as the path to the offsite archival and analysis system.

b) The owner's BACnet communications network (if different from the above) – to serve as the connection to the BAS.

2. Final Building Ethernet Connection(s) shall be coordinated with the owner's IT Group.

D. Both the FMS manufacturer and FMC shall have quality control procedures for design and manufacture of Facility Monitoring Systems for precision monitoring, indoor air quality, energy savings and preventative maintenance.

E. The FMC shall provide all zone attribute data and programming and shall coordinate object naming conventions and network map requirements with the owner's internal BAS department. The naming convention shall be submitted with the FMC Shop Drawings for review and approval by owner's BAS department.

2.5 SYSTEM OVERVIEW

1. The purpose of the FMS is to establish with extreme precision the proper amount of ventilation needed based on analysis of the air within the facility for airborne contaminants. This analysis will involve precise comparison between air within any space being ventilated and the air being supplied to it, the air outside the building, or both as indicated in specific applications.

2. Data captured during the analysis and through the ventilation management process will be analyzed and formatted into a host of on screen displays, analytical reports, and analysis based notification of operational deficiencies. These analyses will encompass data sets gathered over time, and should not be confused with simple alarm notifications.

A. AIR DATA ROUTERS

1. The Air Data Router shall be furnished as a complete, self-contained, unit housing all electronics, air solenoid valves, sampling manifolds, firmware, and software. Unit shall be furnished with all internal devices and wiring assembled and tested at the factory.

2. The Air Data Router shall feature backbone connections capable of accepting OSC Structured Cable for the purpose of daisy chaining all ADRs. MD Tubing and OT Tubing shall not be used to daisy chain ADRs.
3. Air Data Routers shall receive commands from the Sensor Suite to open the solenoid valve of each test area to be monitored while simultaneously closing all other solenoid valves in the system. A direct path between the test area being sampled and the virtual sensors located with the Sensor Suite shall be established to draw a continuous stream of air through the OSC backbone and OSC/MD/OT test area connection.
4. Air Data Routers shall consist of an enclosure; terminations areas for both field wiring and Structured Cable and MicroDuct or, with the provision of enlarger fittings (catalog number OT-E11), OT Tubing connections; a communications/processor board; high capacity solenoid valves; and sampling manifold.
5. Air Data Router shall have the ability to interface with the OSC Structured Cable, MD Tubing, or OT Tubing. Air Data Router shall utilize an internal, factory pre-assembled air sampling manifold to interface to the on-board solenoid valves, and push to connect speed fittings for ease of interface to the Structured Cable and MD Tubing or, with the provision of enlarger fittings (catalog number OT-E11), OT Tubing. Romex connectors and knockouts shall be factory furnished and installed on the Router.
6. Air Data Routers shall be capable of sampling of up to four locations.
7. Air Data router shall be capable of accepting universal 0−10Vdc or 4−20mA inputs and outputs through expansion boards for interfacing to other third party devices and controllers.
8. Up to 30 Air Data Routers shall communicate on an isolated RS-485 network with the Sensor Suite.
9. All point data, algorithms and application software within the Air Data Routers shall be programmable from the Information Management System. Each Air Data Router shall contain both software and firmware to receive and perform full test sequencing schemes downloaded from the System.
10. Each Air Data Router shall contain a serial port for the interface with a portable computer. Air Data Router and network integration shall be possible through this port.
11. Air Data Routers shall be capable of proper operation in an ambient temperature environment of 40 degrees F to 120 degrees F (4.4°–49°C), 0–90% RH (non-condensing).
12. Air Data Routers shall have LED indication for visual status of communication and power.
13. Air Data Routers shall operate on 24Vac power fed from a common 120/24Vac transformer. Low voltage power shall be distributed to the Air Data Routers through the associated Structured Cable.

B. SENSOR SUITE

1. The Sensor Suite shall be a distributed, network based, multipoint sensing device. The Sensor Suite shall be furnished as a complete, self-contained unit housing all electronics, sensing card cage, sampling manifolds, flow regulators, pressure regulators, firmware, and software.
2. The Sensor Suite shall provide communications between the Air Data Router sub network and the Information Management System over an isolated RS-485 network. The Sensor Suite shall support communications with a sub network of 30 Air Data Routers; 30 other Sensor Suites, and an Information Management System.
3. The Sensor Suite base unit shall consist of an enclosure; hinged door with keyed lock; terminations area for both field wiring and Structured Cable subnet connections for limb A and B; a communications/processor board; electronic flow measurement and controller assembly; and sensor bay.
4. The Sensor Suite shall utilize a card cage to allow for the ease of selection and installation of a diverse array of environmental and specialty sensors. At a minimum, the Sensor Suite shall incorporate the following sensors to meet the required applications:

   [REFER TO APPENDIX D AT THE END OF THIS DOCUMENT AND COPY & PASTE ALL APPLICABLE SENSORS HERE.

   REFER TO APPENDIX A FOR A LIST OF RECOMMENDED SENSORS BY APPLICATION TYPE

   FOR VIVARIUM APPLICATIONS COPY AND PASTE APPENDIX E AT THE END OF THE DOCUMENT.

   FOR LAB EXHAUST FAN DILLUTION CONTROL APPLICATIONS COPY AND PASTE APPENDIX I AT THE END OF THE DOCUMENT.]
5. The Sensor Suite shall have the ability to “multitask” by concurrently drawing an air sample from one limb while sensing the parameters of the air sample in the other limb.
6. The Sensor Suite shall be modular in nature and allow for the addition and removal of the sensors for application specific sensing requirements, and ease of calibration and service.
7. The Sensor Suite shall house an on-board flow regulator, orifice plate, and differential pressure sensor to maintain a continuous, regulated flow rate through the Structured Cable.
8. On-board diagnostics shall continuously perform system checks.
9. The Sensor Suite will continuously monitor atmospheric pressure and compensate sensor outputs accordingly as the atmospheric pressure changes.
10. Each Sensor Suite shall contain a serial port for the interface with a portable computer. Sensor Suite and network integration shall be possible through this port.
11. Sensor Suites shall be capable of proper operation in an ambient temperature environment of 40 degrees F to 120 degrees F (4.4°–49°C), 0–90% RH (non-condensing).
12. Sensor Suites shall have LED indication for visual status of communication and power.
13. Sensor Suites shall operate on 24Vac power fed from a common 120/24Vac transformer connected to the Sensor Suite provided by the FMC.
14. To mitigate the potential for Sensor Suite failure, the Sensor Suite shall not be mounted to the same support structure as the vacuum pumps.

C. HIGH FLOW VACUUM PUMP

1. EACH Sensor Suite will be equipped with a High Flow Vacuum Pump (HFP) that will draw samples from the sampling ports in the system, through the Sensor Suite, and then discharge them. Samples will be discharged **[CHOOSE ONE] [into the pump room.] OR [into the nearest exhaust duct so the samples may be discharged directly from the building.]**

2. EACH Sensor Suite will be provided with a Pump Control Module (PCM) card for monitoring system vacuum pressure and, for systems featuring dual pump systems, controlling automatic pump switchover upon primary pump failure.

3. The HFP105/106/205/206 will meet the following specifications:

   a) Minimum Vacuum Pressure: -8.5 PSIg

   b) Minimum Flow Rate: 29 LPM (1.02 SCFM)

4. Pump mounting: Pump shall be mounted securely using the factory supplied mounting assembly to prevent it from moving due to vibration, and in a location where the sound of the pump will not be heard outside the immediate area. The pump mounting assembly shall not be secured to the same structure as the IMS or Sensor Suite.

5. **[OPTIONAL]** Standby pump with automatic switchover: Provides a second pump, identical to the first, with an automatic switchover controller that will automatically take over should the on-line pump stop for any reason other than a complete failure of all local AC power. In the event this occurs, or if some other event occurs resulting in a loss of vacuum at the SST, the standby pump will be placed in operation and a notification will be sent to the Aircuity remote monitoring team, notifying customer support that the backup pump is in operation, prompting a field visit. At any point, if there is a sustained loss of vacuum at the SST, a notification will be sent to the Aircuity remote monitoring team, and all BACnet points whose integrity is affected by the loss of vacuum condition will be marked as “unreliable”, which can be observed by the BMS, so that they can respond accordingly. The notification will be reset once the loss of vacuum condition is remedied.

D. INFORMATION MANAGEMENT SYSTEM

1. The Information Management System (System) shall provide network management of Sensor Suites, integration to the BAS, and interface to MyAircuity.com for viewing and outputting graphs, charts and data derived from the Ventilation Management System.
2. The hardware platform for the System shall, at a minimum, consist of:
   a. Operating System shall be Windows 10, 64-bit
   b. Minimum 1.83 GHz processor speed.
   c. Minimum 8GB on board RAM
   d. Solid-state drive or equal high-speed data storage, minimum 250 gigabytes.
   e. Two (2) Gigabit LAN connections: (10/100)
   f. Dual RS-232 Serial Ports
3. The owner shall provide CAT-5e or CAT-6 network drops and cabling between the FMS Information Management System and:
   a. The owner's Building Ethernet Network - to serve as the path to the offsite archival and analysis system (the Aircuity Cloud)
   b. The owner's BACnet communications network (if different from the above) – to serve as the connection to the BAS.
   c. Final Building Ethernet Connection shall be coordinated with the owner's IT Group.
4. The System shall be located within 25' (6.4 m) of the nearest Sensor Suite and be connected to the System through the RS-232 serial port.
5. To mitigate potential damage to the IMS, the IMS shall not be mounted to the same support structure as the vacuum pumps.

E. OSC STRUCTURED CABLE

1. The FMS shall utilize a pre-engineered system of Structured Cable to facilitate network wide communications, distribution of low voltage power to Air Data Routers and Sensor Suites, and provide a sampling conduit for air samples all within a single cable.

2. The cable shall contain the necessary wires to distribute communications, data and low voltage power throughout the FMS. As a minimum, Structured cable shall consist of:

   a) Communications – 22 AWG twisted shield pair with drain wire

   b) Low Voltage Power – 18 AWG, 3 wire

3. An inner pathway, MicroDuct, shall be furnished as an integral part of the OSC Structured Cable to facilitate collection of zone air samples. MicroDuct shall be lined with a smooth, electrically conductive, chemically inert surface to ensure air samples remain pure and uncorrupted and do not adhere to the wall lining during transport.

4. Structured Cable shall not require any specialized tools for installation. Installation of the cable shall follow traditional local area network practices.

5. Structured Cable shall carry incremental length markings (in feet) throughout the cable length.

6. The minimum length of Structured Cable run between an ADR test area connection and an end device shall be no shorter than 20' (6.1 m).

7. **[ALTERNATE]** Alternate provision for furnishing Structured Cable shall be to furnish:

   a) A dedicated air sampling network interconnecting the Air Data Routers, Sensor Suites, and room/duct probes consisting of Type 304 Stainless Steel Welded Tubing 5/16" OD, .273" ID, .020" Wall. Compression fittings and couplings shall be used and be a minimum of Type 304, or 316L Stainless Steel. Traditional copper, plastic tubing, or variants thereof used in pneumatic controls or other processes shall not be acceptable.

   b) Dedicated wiring specifically used for the FMS consisting of a minimum of:

      1) Communications – 22 AWG twisted shield pair with drain wire

      2) Low Voltage Power – 18 AWG, 3 wire

F. MD TUBING (Non-Lab/Non-Viv Applications without Temperature)

1. The FMS shall utilize a pre-engineered system of MD Tubing to provide a low-cost sampling conduit for air samples in Non-Lab or Non-Vivarium spaces which do not require dry bulb temperature to be measured.

2. The pathway, MicroDuct, shall be lined with a smooth, electrically conductive, chemically inert surface to ensure air samples remain pure and uncorrupted and do not adhere to the wall lining during transport.

3. MD Tubing shall not require any specialized tools for installation. Installation of the cable shall follow traditional local area network practices.

4. MD Tubing shall carry incremental length markings (in feet) throughout the cable length.

5. The minimum length of Tubing run between an ADR test area connection and an end device, either wall or duct probe, shall be no shorter than 20' (6.1 m).

6. **[ALTERNATE]** Alternate provision for furnishing MD Tubing shall be to furnish:

   a) A dedicated air sampling network interconnecting the Air Data Routers and room/wall/duct probes consisting of Type 304 Stainless Steel Welded Tubing 5/16" OD, .273" ID, .020" Wall. Compression fittings and couplings shall be used and be a minimum of Type 304, or 316L Stainless Steel. Traditional copper, plastic tubing, or variants thereof used in pneumatic controls or other processes shall not be acceptable.

G. OT TUBING (CO2/CO Applications only)

1. The FMS shall utilize a pre-engineered system of OT Tubing to provide a low cost sampling conduit for air samples when the only contaminants of concern are either carbon dioxide (CO2) or carbon monoxide (CO).

2. OT Tubing shall be 0.375" OD x 0.25" ID (0.95 OD x 0.64 ID cm), dimensionally stable and shall conform to NFPA 90A flame and smoke spread indices for return air plenum installations.
3. OT Tubing shall not require any specialized tools for installation. Installation of the Tubing shall follow traditional local area network practices.
4. OT Tubing shall carry incremental length markings (in feet) throughout the Tubing length.
5. OT Tubing shall require the use of enlarger fittings (catalog number OT-E11) for all OT Tubing connections made to ADRs and duct probes. Enlarger fittings shall not be required for connecting OT Tubing to Room Probes.
6. The minimum length of Tubing run between an ADR test area connection and an end device shall be no shorter than 20' (6.1 m).

H. VACUUM PUMP SYSTEM TUBING

1. Vacuum Tubing shall be 0.5" OD x 0.375" ID (1.27 OD x 0.95 ID cm), dimensionally stable and shall conform to NFPA 90A flame and smoke spread indices for return air plenum installations
2. Vacuum Tubing shall not require any specialized tools for installation. Installation of the Tubing should follow the customer’s building standards.

I. ROOM, WALL, DUCT, and OUTSIDE AIR PROBES

1. Room Probes:
   a. A semi-flush mounted, sampling port with an optional integral temperature sensor housed within one enclosure; the port within the enclosure will accept the MicroDuct from the Structured Cable or OT Tubing (for CO2/CO only applications).
   b. Temperature Sensing Element: **[DELETE THIS IF NO TEMPERATURE SENSOR IS DESIRED]**

      Platinum RTD: range -30–130°F (-34–54°C)

      Accuracy: ± 0.30 °F (± .17°C)
   c. Internal coarse filter to screen out large particulate matter from entering the MicroDuct or OT Tubing.
2. Wall Probes:
   a. A semi-flush mounted, architecturally pleasing, wall mounted sampling port; the probe will accept the MicroDuct from the Structured Cable, MD Tubing, or OT Tubing (for CO2/CO applications only).
   b. Internal coarse filter to screen out large particulate matter from entering the MicroDuct.
3. Duct Probe – Duct and Outdoor Air Mount
   a. A duct temperature sensor and air sample probe is to be mounted within one enclosure. Duct sample probe to accept integral MicroDuct from Structured Cable and MD Tubing or, with the provision of an additional enlarger fitting (catalog number OT-E11), OT Tubing (for CO2/CO only applications).
   b. Temperature Sensing Element: **[DELETE THIS IF NO TEMPERATURE SENSOR IS DESIRED]**

      Platinum RTD: range -30–130°F (-34–54°C)

      Accuracy: ± .30 °F (± .17°C)
   c. Internal coarse filter to screen out large particulate matter from entering the MicroDuct or OT Tubing.
   d. Outdoor Air Locations – A NEMA 4X weatherproof enclosure shall be provided.

4. Outside Air Probe

   a. A duct temperature sensor and air sample probe is to be mounted within one enclosure. Duct sample probe to accept integral MicroDuct from Structured Cable and MD Tubing or, with the provision of an additional enlarger fitting (catalog number OT-E11), OT Tubing (for CO2/CO only applications).

   b. Temperature Sensing Element: **[DELETE THIS IF NO TEMPERATURE SENSOR IS DESIRED]**

      Platinum RTD: range -30–130°F (-34–54°C)

      Accuracy: ± .30 °F (± .17°C)

   c. Internal coarse filter to screen out large particulate matter from entering the MicroDuct or OT Tubing.

   d. NEMA 4X Weatherproof enclosure

   e. Probe is to be mounted in a location where it will not be exposed to direct sunlight.

F. Sensors:

1. Sensors are the property of Aircuity whose warranty is covered under the Aircuity Services Commitment agreement.
2. Sensors shall be installed in a listed enclosure (the Sensor Suite) in a climate-controlled environment which is maintained between 40°F–120°F (4.4°C–49°C) and 0–90% RH (non-condensing).
3. Quality of sensors: All sensors shall possess the properties published in section 2.5-B.4 of this specification. For each set of installed sensors a certificate of calibration shall be made available for viewing on MyAircuity.com.
4. Sensors shall be physically removed from the sensor suite, and replaced with freshly calibrated sensors a minimum of every 6 months after the initial sensor installation.
5. Immediately after replacement, sensors are to be shipped back to Aircuity in the postage paid return box provided by Aircuity.

2.6 SYSTEM SOFTWARE OVERVIEW

A. The FMC shall provide all software required for configuration, operation and commissioning of the FMS system specified herein. All functionality described herein shall be regarded as a minimum. The FMC shall provide the following as a minimum:

1. Completed database.
2. Configuration of all Air Data Router, Sensor Suite, System and user interface application programs.
3. All Configuration Tools, and all software licenses, required to configure and operate all products installed on this project.
4. The ability to override raw sensed data for the purposes of commissioning the system after integration with a BMS.

B. SYSTEM CONFIGURATION

1. Database Creation and Modification. All changes shall be done utilizing standard procedures. The system shall allow changes to be made at the local site through the Information Management System.

C. WEB-BASED USER INTERFACE AND DATA MANAGEMENT SYSTEM

1. Included with the system shall be a fully integrated web-based user interface and data management system. The data management system shall be password protected and shall be able to store sampled data from all zones for online viewing and reporting.
2. The data management system will be sized to record and retain every sample taken by the system, along with other data gathered from other systems or direct interface points. The

current calendar year plus two previous complete calendar years will be accessible in an active high-performance database. All data older than that will be archived and made available upon request.

3. Unlimited data access, viewing, report generation and remote data storage shall be provided with the FMS for the duration of the project commissioning and for the entire warranty period.
4. The web-based user interface and data management system includes detailed analysis of ventilation performance and other operating conditions based on data gathered over time.
5. At the start of the Warranty period the FMC will transmit to the owner an agreement marked “PAID IN FULL” that will provide these services for a period of [XX] years.
6. The web-based user interface and data management system will also send automated notifications and summary reports to a user defined e-mail distribution list. These notifications will be issued based on the time based analysis, and should not be confused with simple alarm messages.

2.7 SUBMITTALS

A. As soon as Submittals are prepared, an electronic version shall be provided simultaneously with the mailing of the paper copies. This version shall be transmitted in electronic format, via e-mail, to expedite the approval process.

B. Shop Drawings shall include:

1. Index: The first sheet of the Shop Drawings shall be an Index of all sheets in the set.
2. Legend: A description of symbols and acronyms used shall be provided at the beginning of the set of Shop Drawings.
3. Communications Riser: A single-page diagram depicting the system architecture complete with a communications riser. Riser shall include room locations and addressing for each Air Data Router and Sensor Suite. Include a Bill of Material for all equipment in this diagram but not included with the unique controlled systems.
4. Device Addressing Scheme: Install controllers implementing an addressing scheme consistent with a reference-document. The addressing scheme shall be submitted, reviewed and approved by the owner’s BAS Group prior to implementation.
5. Equipment Numbering: Equipment numbering scheme shall be submitted, reviewed and approved by the owner’s BAS Group prior to implementation.
6. Systems Summary: Drawings shall include a table listing each piece of equipment and the area(s) served by each piece of equipment.
7. System Schematic: Drawings shall include a single-line representation of all areas being monitored and/or controlled, including all field devices required for properly controlling equipment and implementing the sequences of operation for this project.
8. Point-to-point Wiring Details: Drawings shall include point-to-point wiring details and must show all field devices, routers, sensor suites, controllers, panel devices, wiring terminal numbers and any special information (i.e. shielding requirements) for properly monitoring areas and controlling equipment.
9. Bill of Material: Drawings shall include a bill of the material necessary and used for properly controlling equipment and implementing the required sequences of operation.
10. Configuration Details: Drawings shall include test and cluster sequence schedules for each test point.
11. As-Built Drawings and documentation shall be created after the final system checkout, by modifying and adding to the Shop Drawings and completing the Aircuity system vacuum decay worksheet. As-Built Drawings shall show exact installation locations of equipment as well as indicate installed cable paths and lengths. As-Built Drawings will be acknowledged in writing by the project design engineer and the owner’s representative after the final checkout of the system. The system will not be considered complete until the As-Built Drawings have

received their final approval. The FMC shall provide four sets of As-Built Drawings.

C. Operation and Maintenance Manuals

1. Operation and Maintenance (O&M) manuals for the system shall include project specific, detailed information describing the specific installation. Manual shall contain as a minimum:

a) System overview

b) Networking architecture

c) Hardware cut-sheets and product descriptions

d) Wiring diagrams for all controllers and field hardware

2.8 WARRANTY

A. Repair or replace any defective product not covered by Hardware Assurance (see section 2.9.A.2 below) and correct any defect in material or workmanship for a period of 36 months following date of shipment.

2.9 AIRCUITY SERVICES COMMITMENT AGREEMENT

A. At the time of sensors are shipped from the factory as described later in this specification, the FMC will transmit an agreement for annual services to the owner marked “PAID IN FULL” that will provide services for the system for a period of **[XX]** years. Under this agreement the FMC will provide four services: MONITORING, SENSOR ASSURANCE, HARDWARE ASSURANCE AND REPORTING.

1. Monitoring: Monitoring is both predictive and diagnostic and evaluates the performance of the mechanical and electrical components.

a) Data Upload: Verification is performed on every test area to ensure itis uploading correctly.

b) System Events: The system is scanned for proper functionality and is checked for such events as leak test status and communication hardware status.

c) Sensor Performance: All sensors have a designated life span which is why sensor performance is reviewed for a number of conditions including out of range, failure, and calibration due date. Any issues found are either solved remotely or by sending Aircuity certified service technicians.

2. Sensor Assurance: Sensor element replacement, calibration services, diagnostics, firmware upgrades, materials and equipment necessary for ongoing system operation. At a minimum, twice a year, provide calibration with NIST traceable calibration gases and test instrumentation, functional testing, sensor element evaluation to determine useful life and element replacement as required, and evaluation services to insure the ongoing performance of all sensors as installed system per this specification. This service shall include, but not be limited to the following:

a. Sensor Calibration: Sensors require periodic calibration to ensure their long-term accuracy and reliable performance. All sensors undergo scheduled factory recalibration twice per year. These factory performed services include sensor calibration and a functional test of the unit based on the sensor manufacturer’s instructions. A calibration certificate is available for each sensor, which contains information on calibration settings and the values obtained during its full range of testing.

b. Sensor Exchange: Every six months, freshly calibrated sensors will be shipped from Aircuity’s Calibration Laboratory to the Aircuity representative for installation at the Sensor Suite. The representative will exchange the calibrated sensor for the one currently in the system and return the previous sensor to the factory in the prepaid package. Aircuity manages this process for the life of the active system to eliminate the risk of sensor failure and the headaches of scheduling sensor exchanges.

c. Sensor Element Replacement: The sensor element is the internal component that performs the actual sensing. Sensor elements are consumed, wear out, and/or become inactive over time as a natural part of their operation. Sensor element replacement is performed as required during the course of sensor calibration at no additional charge to the customer. As the element degrades and/or wears out over time, it is routinely replaced to assure the Aircuity system is operating at peak performance.

d. Sensor Hardware: The repair or replacement of any defective sensor component is covered by the hardware aspect of Sensor Assurance.

e. Sensor Firmware: Periodic software updates are covered by the firmware aspect of Sensor Assurance.

3. Hardware Assurance: Aircuity's system is designed to be a long-term solution. Certain subcomponents of the system have a calculated life span; Aircuity's Hardware Assurance will provide for the replacement of the vacuum pump and Information Management System. This service makes certain that the components of an Aircuity system are operating at their peak performance for years to come.

4. Analytics and Graphing & Exporting: Your daily view and deeper dive on building performance are both here.

a) The Analytics available on MyAircuity.com are capable of providing a daily view of your savings, system performance, and occupant behavior. Building data from other systems can be integrated through the BMS, enhancing the diagnostic capabilities of the analytics. Depending upon your type of building and level of integration, you may have access to the following analytics:

1) Overall System Summary and Airflow Reduction Data: A brief description of your installed system and its lifetime performance is provided along with a breakdown of how much of a reduction in airflow was achieved due to the installation of your Aircuity system and how this translates into airflow reductions for your building.

2) Trend log: A one-year historical look back at your total actual airflow data compared against your pre-Aircuity total airflow and your targeted post-Aircuity airflow. An average total airflow value for that past years' worth of data is also overlaid over this graph.

3) IEQ Summary: A one week look back at your building's data categorized by each IEQ parameter your system features. This analytic works along with the customer configurable parameter threshold values for each space to alert you of which zones have exceeded their threshold values, how often a zone may have exceeded their threshold values, and how often this may have occurred over the past 7 days. Also, to help determine whether an event is a persistent issue, you also have the ability to see the previous 7 weeks' worth of IEQ Summary Data.

4) Fume Hood Usage-based Analytics: A one week look back at your lab occupants' fume hood usage habits. Individual Fume Hood feedback data is used to determine which fume hoods have been left open (sash has been left open and has not moved for more than 1 hour), which fume hoods are not being used (sash has been left at minimum/closed position and has not moved for 1 hour or more), and which fume hoods are being used normally during this time period. For additional fume hood usage information, candlestick graphs are also provided for each fume hood which helps illustrate the overall range of each fume hood's sash over a specified period of time (user configurable).

5) Service and Maintenance: Based on the start date of your Aircuity Services Commitment, a countdown of when your ASC will expire is provided as well as a countdown to your next bi-annual sensor swap.

b) Graphing & Exporting: This tool is used for a deeper dive into your facility's operation. See an event on your dashboard? Graphing & Exporting allows you to dig deeper into the cause. The available data can also be used for reporting and documentation purposes – the granularity of which is determined by each system's cycle time. Each graph is user configurable over a specified time range and allows the end user to overlay graphical data to observe behavior/responses across multiple zones.

PART 3 EXECUTION

3.1 GENERAL

A. Install all equipment and systems specified herein in accordance with the manufacturer's most current version of the installation guide. In the event of conflicting information between this document and the installation guide, the most stringent requirement shall apply.

B. Verify that mechanical and control systems are complete and ensure that the systems are capable of being started and operated in a safe and normal condition before attempting to operate the FMS.

C. Install software in the Management System. Implement all features of programs to specified requirements and as appropriate for sequence of operation.

D. Connect and configure equipment and software to achieve sequence of operation specified.

3.2 WIRING INSTALLATION

1. Install systems and materials in accordance with manufacturer's instructions, rough-in drawings and equipment details. Install electrical components and use electrical products complying with requirements of applicable Division **[XX]** sections of these specifications.

2. All wiring shall be installed neatly and professionally, in accordance with requirements of applicable Specification Division **[XX]** section and all national, state, and local electrical codes. All the wiring shall be installed in accordance with the current National Electrical Code (NEC).

3. Provide wiring as required by functions as specified and as recommended by equipment manufacturer to serve specified control functions.

4. Install wiring and cables according to Division **[XX]** section and as follows:

   a) Bundle and harness multi-conductor cable in place of single cables where several cables follow a common path.

   b) Fasten flexible conductors, bridging cabinets and doors, along hinge side; protect against abrasion. Tie and support conductors.

5. All exposed control wiring and control wiring in the mechanical, electrical, telephone, and similar rooms shall be installed in raceways. All other wiring shall be installed neatly and inconspicuously.

6. All control wiring shall be installed in a neat and workmanlike manner parallel to building lines with adequate support. Both conduit and plenum wiring shall be supported from or anchored to structural members. Conduit or plenum wiring supported from or anchored to piping, duct supports, the ceiling suspension system, is not acceptable. Wiring buried in slab-on-grade concrete or explosion-proof areas shall be in rigid metal conduit. Provide adequate strain relief for all field terminations.

3.3 FIELD DEVICE INSTALLATION

A. All room and wall probes shall be mounted so as to be accessible in accordance with ADA Guidelines, unless otherwise noted on the drawings.

A. Freestanding enclosures and panels shall be supported on steel unistrut frames, or approved equal, and be securely anchored to the floor and be well braced.

B. Enclosures and panels mounted directly to the wall shall be provided with all clearances required by the manufacturer's installation guide.

C. A minimum of 3' (1 m) working clearance shall be provided in front of all enclosures and panels; clearance shall be ensured to permit the enclosure door to open at least 90° from its closed position.

D. Mounting height shall be a maximum 6'-6" (2 m) to the top of the Sensor Suite enclosure.

E. All field devices shall be installed in a location which is easily accessible after installation for the purposes of troubleshooting & future modifications.

F. IMSs and SSTs shall not be installed on the same support structure or wall as the vacuum pump bracket.

3.4 CONTROL POWER

A. Class 2 step-down transformers shall provide 24VAC power for all Air Data Routers, Sensor Suites, and associated FMS components from nearest electrical power panel noted below or as indicated on the electrical drawings—coordinate the installation and location thereof with Electrical Contractor and all other trades.

1. The primary side of all Class 2 step-down transformers shall be fed by dedicated branch circuits with grounding conductors from the nearest building electrical distribution power panel. Branch circuits shall be installed per local state and federal codes by a licensed electrician.
2. The secondary side of all class 2 step-down transformers, used for the purposes of providing power to Air Data Routers, Sensor Suites and associated FMS components, shall not be grounded.
3. It is highly recommended that the IMS and OSI (if applicable) be powered from a power source with power loss and surge protection. The IMS and OSI shall be powered from a 120VAC dedicated power receptacle installed per local state and federal codes by a licensed electrician.
4. Where applicable, all FMS equipment shall be powered by the same source of emergency power as the air handling units and BAS themselves. For example, if the Air Handling units are served by the building's generators, the FMS must also be served by the generators.

3.5 IDENTIFICATION

A. The FMC shall label each system device with a point address or other clearly identifiable notation inside the device cover - labels shall be permanent and typewritten. Use of handwritten labeling with markers is not acceptable. All FMS equipment shall be clearly identified as noted on the approved submittals.

3.6 FINAL INSTALLATION OF CRITICAL SENSORS

A. Sensors will be held at the manufacturer's location and not shipped to the site until checkout & startup of the all other portions of the FMS is complete, and mechanical systems are operational and ready to implement the sequences that will result in ventilation being performed on demand as indicated by the FMS.

B. At the time sensors are shipped the Aircuity Services Commitment agreement marked PAID IN FULL described above will be transmitted to the owner.

3.7 ACCEPTANCE OF COMPLETED FMS INSTALLATION

A. Upon completion of the installation, the FMC shall initiate the Optimization phase of the start-up process for the Aircuity system and perform all necessary calibration, testing, and debugging operations including, but not limited to, the vacuum decay test. An acceptance test shall be performed by the FMC in the presence of the design engineer, job site project manager, and owner's representative. Acceptance test shall be scheduled with at least 10 working days advance notice. Manufacturer's Field Service: Engage a factory-authorized service representative to inspect field-assembled components and equipment installation, including piping and electrical connections.

B. After electrical circuitry has been energized, start units to confirm proper unit operation. Remove malfunctioning units, replace with new units, and retest.

C. Demonstrate compliance with specifications, including calibration and testing, and air sampling test sequences. Adjust, calibrate, and fine tune equipment to achieve sequence of operation specified.

D. The acceptance test shall include, but not be limited to:

1. The FMC shall verify the proper operation of all input/outputs.

2. The FMC shall verify all inputs meet or exceed manufacturer's stated tolerances for accuracy.

3. The FMC shall verify that all on-line graphical displays of air sampling test data accurately represent the real time state of the field conditions.

4. The FMC shall verify the reliability of all communications of all Air Data Routers and Sensor Suites.

5. The test shall include functional verification of all interfaces and system integration required to meet the scope of this project.

6. Participation in a joint session with the BAS contractor to demonstrate that the complete sequence of operation is being executed accordingly.

A. Acceptance: When the field test procedures have been successfully demonstrated to the design engineer, job site project manager, or owner's representative and the system performance is deemed satisfactory, the system parts will be accepted for beneficial use and placed under warranty. At this time, a "notice of completion" shall be issued by the owner's representative and the warranty period shall start.

3.8 TRAINING

A. The FMC shall provide factory-trained instructor to give full instructions to designated personnel in the operation, maintenance, and programming of the system. Instructors shall be thoroughly familiar with all aspects of the subject matter they are to teach. The training shall be specifically oriented to the system and interfacing equipment installed.

B. Instructions shall include 2 parts, the "New Equipment Orientation" and the "Product & Service Training".

C. New Equipment Orientation: A "walk-through" session shall include showing where all field equipment is located throughout the area involved in the project.

D. Product & Service Training: Train on-site personnel on the navigation and interpretation of the data and information provided by the system.

1. Train personnel on procedures and schedules for troubleshooting, servicing, and maintaining equipment.

2. Train personnel on using the web based user interface and data management system.

Appendix A

LIST OF RECOMMENDED SENSORS BY APPLICATION TYPE

FOR APPLICATIONS NOT LISTED BELOW, OR FOR GENERAL QUESTIONS CONTACT THE AIRCUITY APPLICATIONS ENGINEERING DEPARTMENT

APPLICATION	SENSORS												
	CO_2				Dewpoint		Particles		CO	TVOCs			
	SEN-CO2-2A	SEN-CO2-2B	SEN-CO2-3	SEN-C2D-3	SEN-DPT-2	SEN-C2D-3	SEN-PAR-1	SEN-PAR-2	SEN-COM-1	SEN-TVC-1	SEN-TVC-1&2	SEN-TVC-1&3	EFS-TVC-1&3
Traditional/Office DCV (without control of chilled beams)	O	O	✓	O	O	O	O	O	O	O	O	X	X
Traditional/Office DCV (with control of chilled beams)	⊘	⊘	⊘	**R**	⊘	**R**	O	O	O	O	O	X	X
Laboratory DCV (without control of chilled beams)	O	O	O	✓	O	✓	**R**	O	O	O	**R**	X	X
Laboratory DCV (with control of chilled beams)	⊘	⊘	⊘	**R**	⊘	**R**	**R**	O	O	O	**R**	X	X
Vivarium DCV	O	O	O	✓	X	✓	X	**R**	O	X	X	**R**	X
Parking Garages/Locations with Fossil Fuel Powered Equipment	X	O	O	✓	X	✓	O	O	✓	O	✓	X	X
Laboratory Exhaust Fan System Control	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	**R**

LEGEND	
Optional	O
Not Permitted	⊘
Recommended	✓
Not Recommended	X
Required	**R**

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Appendix B

(FOR JOBS REQUIRING INTEGRATION USING BACNET)

The following sections must be added to the Building Automation System (BAS) section of the specification in order to ensure optimum facility performance.

1. FACILITY MONITORING SYSTEM INTERFACE

A. The building will be equipped with a Facility Monitoring System (FMS) as specified in other sections of these specifications. The purpose of the system is to analyze key elements of the indoor environment and to provide direction to the mechanical systems via the BAS. Directions to be achieved shall be accomplished by monitoring and analysis of airborne parameters such as particulates, volatile organic compounds (VOCs), moisture content, gases such as carbon monoxide and carbon dioxide (CO, CO2), and others as indicated in the FMS specification. As a result of this analysis the FMS will provide the BAS with changes in operational parameters, most significantly airflow rates. The system will also provide analysis of how the indoor environment responds as a result of the mechanical system modes of operation, and provide optional performance reports and other data to building management.

B. The BAS contractor shall be required to implement an interface between the BAS and the FMS which shall communicate with the BAS via BACnet.

1. The BAS contractor shall be responsible for:

a. Obtaining and reading the most current copy of Aircuity's Protocol Implementation Conformance Statement (PICS).

b. Registering the FMS with the BAS so it is a recognized component in the BAS, by providing a unique BACnet Device Object Instance Number, and static IP Address.

c. The creation of the necessary BACnet Objects in the BAS' database which allow for the inclusion of the FMS' signals to be mapped over for the purposes of control or so the data may be displayed on the front end.

d. The exposure of the necessary BACnet Objects' present value and reliability properties over the BACnet network to allow for the FMS to pull in the necessary feedback values using the BACnet Client Service.

e. If applicable, the BAS shall also write all present value and reliability property feedback values for all points requested by the FMC to the BACnet Objects created in the FMS and exposed over the BACnet network. After the creation of their project file, the FMC shall furnish an exported 'points list' to the BAS to assist with this effort.

f. All failsafe responses. Failsafe responses are typically pre-Aircuity values or values if Aircuity were to be removed from the project. The BAS contractor shall confirm all failsafe responses with the project engineer.

g. Implementing the necessary control sequences to respond to the directions from the FMS. The BAS shall be responsible for prioritizing all command signals so that life safety control functions and safe HVAC design practices (such as smoke control and room offsets) are not overruled by Aircuity's recommended ventilation command signal.

h. Provide qualified on-site staff during start-up of the FMS to ensure that communication is functional, that data values are received from the FMS, that control BAS sequences as a result of this data are implemented properly and effectively, and that necessary data is transmitted to the FMS.

i. In a Lab, Vivarium or other Critical Environment the BAS shall at a minimum provide the following flow feedbacks that are being commanded as a result of the FMS information. This flow feedback shall be written to the Aircuity IMS via BACnet WRITE PROPERTY Service (DS-WP-A), unless otherwise stated:

(1) The summed total or individualized supply air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

(2) The summed total or individualized return air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

j. The BAS contractor shall communicate, in writing, to the FMS contractor the required formats of all airflow command signals generated by the FMS (i.e. BAS requires all ventilation commands to be in units of CFM)

2. The BAS contractor shall be responsible for reading the FMS' exposed command signal values (both present values and reliability properties) as inputs to the BAS/LACS to determine values such as minimum outside air levels, overall ventilation rates, humidity levels, and others as indicated in the specification or on the drawings, at a rate of once a minute.

a. For LAB/VIV/MpDCV applications the BAS shall, at a minimum, read the following points:

1) Each space's MpDCV CMD signal in units of ACH and/or CFM and its associated reliability status. If these points go unreliable, the BAS shall command the associated space's HVAC system to a predetermined failsafe response.

b. For Differential Energy Economizer Applications, the BAS shall, at a minimum, read the following points:

1) Each AHU's associated Differential Energy Economizer binary output value.

c. For Laboratory Exhaust Fan Control Applications, the BAS shall, at a minimum, read the following points:

1) Each Lab Exhaust Fan System's DCV output signal (in units of ppm as isoB)

3. **[DELETE THIS SECTION IF USING BACNET CLIENT EXCLUSIVELY TO PULL IN FLOW FEEDBACK DATA]** The BAS shall be responsible for writing all feedback values to the FMS that are indicators of the ventilation system and other components in the building at a rate of once a minute, and not on change of value.

These points shall be written to the Aircuity IMS via BACnet WRITE PROPERTY Service (DS_WP-A). Unless otherwise stated, the following points are required to perform analytic functions:

a. To calculate Air Change Rate

1) The summed total (or individualized) supply air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

2) The summed total (or individualized) general exhaust air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

3) A means of determining effective occupancy state of the space

a) A binary BACnet variable to reflect effective occupied state

b) A schedule that reflects the typical occupancy schedule

b. To perform fume hood analytics:

1) Fume hood flow feedback (free of any erroneous purge or alarm status airflow values)

2) Representation of fume hood sash opening percentage

3) Representation of fume hood occupancy state

c. The BAS contractor shall communicate, in writing, to the FMS contractor the formats of each of the above feedbacks (All airflow values shall be in units of CFM.)

d. The BAS shall write additional points to the FMS as prescribed by the engineer.

4. **[DELETE THIS SECTION IF NOT USING BACNET CLIENT TO PULL IN FLOW FEEDBACK DATA]** The BAS contractor shall be responsible for exposing all feedback values to the FMS that are indicators of the ventilation system and other components in the building.

These points shall be read by the Aircuity IMS via BACnet READ PROPERTY Service (DS_RP-A). Unless otherwise stated, the following points are required to perform analytic functions:

a. To calculate Air Change Rate

1) The summed total (or individualized) supply air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

2) The summed total (or individualized) general exhaust air flow feedback values (free of any erroneous purge or alarm status airflow values) from each zone VAV box/valve

3) A means of determining effective occupancy state of the space

a) A binary BACnet variable to reflect effective occupied state

b) A schedule that reflects the typical occupancy schedule

b. To perform fume hood analytics:

1) Fume hood flow feedback (free of any erroneous purge or alarm status airflow values)

2) Representation of fume hood sash opening percentage

3) Representation of fume hood occupancy state

c. The BAS contractor shall communicate, in writing, to the FMS contractor the formats of each of the above feedbacks (All airflow values shall be in units of CFM)

d. The BAS shall expose additional points to the FMS as prescribed by the engineer.

Appendix C

(FOR JOBS REQUIRING HARDWIRED INTEGRATION)

The following sections must be added to the Building Automation System (BAS) section of the specification in order to ensure optimum facility performance.

1. FACILITY MONITORING SYSTEM INTERFACE

A. The building will be equipped with a Facility Monitoring System (FMS) as specified in other sections of these specifications. The purpose of the system is to analyze key elements of the indoor environment and to provide direction to the mechanical systems via the LACS. Directions to be achieved shall be accomplished by monitoring and analysis of airborne parameters such as particulates, volatile organic compounds (VOCs), moisture content, gases such as carbon monoxide and carbon dioxide (CO, CO_2), and others as indicated in the FMS specification. As a result of this analysis the FMS will provide the LACS with changes in operational parameters, most significantly airflow rates. The system will also provide analysis of how the indoor environment responds as a result of the mechanical system modes of operation, and provide optional performance reports and other data to building management.

B. BAS CONTRACTOR'S RESPONSIBILITY: The BAS contractor shall be required to implement an interface between the LACS and the FMS. Expansion boards on the ADRs shall communicate with the LACS via hardwired I/O connections. The BAS contractor shall be responsible for:

1. Providing, routing and terminating all 18 ga. stranded 2-conductor communication wiring between the LACS and FMS' ADR expansion boards. Wiring methods shall match BAS wiring methods and shall conform to local state and federal building codes.
2. Providing the FMS with the following feedbacks for EACH control/pressurized zone:
    a. Total Supply Air Flow Feedback
    b. Total General Exhaust Flow Feedback
    c. Control/pressurized Zone Occupancy Status Value (or provide a written schedule which reflects typical occupancy)
    d. Fume Hood Flow Feedback (for EACH fume hood contained in each control/ pressurized zone)
    e. Fume Hood Occupancy Status (for EACH fume hood contained in each control/pressurized zone)
    f. Fume Hood Sash Open % (for EACH fume hood contained in each control/pressurized zone)
3. Communicating, in writing, to the FMS contractor the formats of each of the above feedbacks (i.e. SA Flow Feedback of 0–10VDC equates to 0–1,000 CFM for Room 101)
4. Reserving or providing the physical inputs required on the LACS for the FMS supply air ventilation command output for EACH control/pressurized zone.
5. Communicating, in writing, to the FMS contractor the required formats of the previously mentioned supply air ventilation commands for EACH space (i.e. 0–10VDC equates to 0–18ACH, or 4–20mA equates to 0–18ACH, etc.)
6. Providing the FMS contractor with a detailed point-to-point wiring diagram package showing the physical terminations on both the LACS and corresponding terminations on the ADR expansion boards.
7. Implementing the necessary control sequences to respond to the directions from the FMS. These directions will be integrated from a priority standpoint so that other control actions such as smoke control are not impeded.
8. Provide qualified on-site staff during start-up of the FMS to ensure that communication is functional, that data values are received from the FMS, that control BAS sequences as a result of this data are implemented properly and effectively, and that necessary data is transmitted to the FMS.

Appendix D

Select the appropriate Sensors from the following pages and insert into Section 2.5-B.4.

THEN DELETE THIS APPENDIX

Sensor Specifications: Carbon Dioxide / Carbon Dioxide & Dewpoint Temperature

Model Number	SEN-CO2-2A	SEN-CO2-2B	SEN-CO2-3	SEN-C2D-3
Typical Application	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based DCV or Monitoring; Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control**
Sensor: Carbon Dioxide (CO2)				
Element	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	0−3000 ppm	0−3000 ppm	0−2000 ppm	0−3000 ppm
Accuracy	± 60 ppm up to 1000 ppm	± 75 ppm up to 1000 ppm	± 45 ppm up to 1000 ppm	± 45 ppm up to 1000 ppm
Repeatability	± 5 ppm	± 9 ppm	± 2 ppm	± 3 ppm
Resolution	3 ppm	3 ppm	2 ppm	3 ppm
Response	25 seconds	10 seconds	10 seconds	10 seconds
Sensor: Dewpoint Temp (DPT)				
Element				Dual Wavelength, Non-Dispersive Infrared Sensor
Range				-58 to ambient DPT Deg F or 122 Deg F, whichever is less
Accuracy				Dewpoint: ± .9 Deg F (± .5 Deg C) from 20 to 65 Deg F DPT RH: @ 65°F and ± .5°F ± 3% RH @10−60% RH ± 4% RH @ 61−90% RH
Response				10 seconds

**Relative Humidity and Enthalpy measurements are computed from dewpoint and drybulb temperatures. Therefore, a local drybulb temperature sensor is required via a room probe, duct probe or outdoor air probe.*

Sensor Specifications: Dewpoint Temperature / Dewpoint Temperature & Carbon Dioxide

Model Number	SEN-DPT-2	SEN-C2D-3
Typical Application	**Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control**	**Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control; CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**
Sensor: Dewpoint Temp (DPT)		
Element	Capacitive Polymer Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	0 to ambient DPT Deg F or 70 Deg F, whichever is less	-58 to ambient DPT Deg F or 122 Deg F, whichever is less
Accuracy	Dewpoint: ± 2 Deg F RH: @ 65°F and ± .5°F ± 6% RH @ 10−60% RH ± 8% RH @ 61−90% RH	Dewpoint: ± .9 Deg F (± .5 Deg C) from 20 to 65 Deg F DPT RH: @ 65°F and ± .5°F ± 3% RH @10−60% RH ± 4% RH @ 61−90% RH
Response	30 seconds	10 seconds
Sensor: Carbon Dioxide (CO2)		
Element		Dual Wavelength, Non-Dispersive Infrared Sensor
Range		0−3000 ppm
Accuracy		± 45 ppm up to 1000 ppm
Resolution		3 ppm
Response		10 seconds

**Relative Humidity and Enthalpy measurements are computed from dewpoint and drybulb temperatures. Therefore, a local drybulb temperature sensor is required via a room probe, duct probe or outdoor air probe.*

Sensor Specifications: Airborne Particulates

Model Number	SEN-PAR-1	SEN-PAR-2
Typical Application	**Particulate Monitoring or Control: May be used in any application**	**Particulate Monitoring or Control: Designed for use in Vivariums, Healthcare Facilities, Clean Rooms and other Applications**
Sensor: Airborne Particulates - Small Particles PM2.5	Single Channel	Dual Channel
Element	Optical Particle Counter	Optical Particle Counter
Range	PM2.5: 0.3−2.5µm	PM2.5: 0.3−2.5µm, 0.5−2.5µm, 0.3−2.5 µm
Accuracy	± 25% of reading	± 25% of reading
Concentration Range	100−10,000,000 particles pcf	100−10,000,000 particles pcf
Response	30 seconds	30 seconds

Sensor Specifications: Total Volatile Organic Compounds

Model Number	SEN-TVC-1	SEN-TVC-1&2	EFS-TVC-1&3
Technology	**MOS**	**MOS/PID**	**MOS/Enhanced PID**
Typical Application	**Utilizing the MOS sensing for monitoring only of non-critical ventilation applications.**	**Combines the MOS and PID sensing technology into a single assembly, while supporting the individual sensing capabilities of each. This configuration is recommended for monitoring only or for control of critical spaces such as research labs.**	**Combines the MOS and an enhanced version of the PID sensing technology into one single assembly that is designed for use in the monitoring of exhaust plenum Demand Based Control (DBC) of exhaust fans.**
Sensor: TVOCs			
Technology	**MOS**		**PID**
Element	Metal Oxide Semiconductor (MOS)		Photoionization Detector (PID)-VOCs & other gases with ionization potentials <10.6eV
Range	**Calibrated Range:** 0−50 ppm (as Isobutylene) **Maximum Range:** 0−100 ppm (as Isobutylene)		**Calibrated Range:** 0−5 ppm (as Isobutylene) **Maximum Range:** 0−20 ppm (as Isobutylene)
Accuracy	± .5 ppm (as Isobutylene) or 25% of reading (whichever is greater)		± .2 ppm (as Isobutylene) or 2.5% of reading (whichever is greater)
Resolution	0.2 ppm		0.025 ppm
Drift Stability	± 15 ppm/6 months @ 50 ppm		± 2 ppm/6 months @ 5 ppm
Response	30 seconds		30 seconds

Sensor Specifications: Carbon Monoxide

Model Number	SEN-COM-1
Typical Application	**Carbon Monoxide Monitoring or Control**
Sensor: COM	
Element	Electrochemical Sensor
Range	0−150 ppm
Accuracy	± 3 ppm or 5% of reading, (whichever is greater)
Resolution	1 ppm

Appendix E

FOR APPLICATIONS USING THE VIVARIUM DCV APPLICATION MODULE ONLY!!!

Insert the following tables into Section 2.5-B.4 then delete this appendix.

Sensor Specifications: Carbon Dioxide / Carbon Dioxide & Dewpoint Temperature

Model Number	**SEN-C2D-3**
Typical Application	**CO2 Based (DCV) or Monitoring - Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control**
Sensor: Carbon Dioxide (CO2)	
Element	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	0−3000 ppm
Accuracy	± 45 ppm up to 1000 ppm
Repeatability	± 3 ppm
Resolution	3 ppm
Response	10 seconds
Sensor: Dewpoint Temp (DPT)	
Element	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	-58 to ambient DPT Deg F or 122 Deg F, whichever is less
Accuracy	Dewpoint: ± .9 Deg F (± .5 Deg C) from 20 to 65 Deg F DPT RH: @ 65°F and ± .5°F ± 3% RH @10−60% RH ± 4% RH @ 61−90% RH
Response	10 seconds

**Relative Humidity and Enthalpy measurements are computed from dewpoint and drybulb temperatures. Therefore, a local drybulb temperature sensor is required via a room probe, duct probe or outdoor air probe.*

Sensor Specifications: Dewpoint Temperature / Dewpoint Temperature & Carbon Dioxide

Model Number	SEN-C2D-3
Typical Application	Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control - CO_2 Based Demand Controlled Ventilation (DCV) or Monitoring
Sensor: Dewpoint Temp (DPT)	
Element	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	-58 to ambient DPT Deg F or 122 Deg F, whichever is less
Accuracy	Dewpoint: ± .9 Deg F (± .5 Deg C) from 20 to 65 Deg F DPT RH: @ 65°F and ± .5°F ± 3% RH @10−60% RH ± 4% RH @ 61−90% RH
Response	10 seconds
Sensor: Carbon Dioxide (CO_2)	
Element	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	0−3000 ppm
Accuracy	± 45 ppm up to 1000 ppm
Resolution	3 ppm
Response	10 seconds

**Relative Humidity and Enthalpy measurements are computed from dewpoint and drybulb temperatures. Therefore, a local drybulb temperature sensor is required via a room probe, duct probe or outdoor air probe.*

Sensor Specifications: Airborne Particulates

Model Number	SEN-PAR-2
Typical Application	Particulate Monitoring or Control: Designed for use in Vivariums, Healthcare Facilities, Clean Rooms and other Applications
Sensor: Airborne Particulates - Small Particles PM2.5	Dual Channel
Element	Optical Particle Counter
Range	PM2.5: 0.3−2.5μm, 0.5−2.5μm, 0.3−2.5 μm
Accuracy	± 25% of reading
Concentration Range	100−10,000,000 particles pcf
Response	30 seconds

Sensor Specifications: Total Volatile Organic Compounds

Model Number	**SEN-TVC-1&3**	
Technology	**MOS/Enhanced PID**	
Typical Application	**Combines the MOS and an enhanced version of the PID sensing technology into one single assembly that is designed to support vivariums and other environments where there are likely to be higher concentrations of adsorptive compounds, such as ammonia. The PID is calibrated to both ammonia and isobutylene.**	
Sensor: TVOCs		
Technology	**MOS**	**PID**
Element	Metal Oxide Semiconductor (MOS)	Photoionization Detector (PID)-VOCs & other gases with ionization potentials <10.6eV
Range	**Calibrated Range:** 0−50 ppm (as Isobutylene) **Maximum Range:** 0−100 ppm (as Isobutylene)	**Calibrated Range:** 0−5 ppm (as Isobutylene) **Maximum Range:** 0−20 ppm (as Isobutylene)
Accuracy	± .5 ppm (as Isobutylene) or 25% of reading (whichever is greater)	± .2 ppm (as Isobutylene) or 2.5% of reading (whichever is greater)
Resolution	0.2 ppm	0.025 ppm
Drift Stability	± 15 ppm/6 months @ 50 ppm	± 2 ppm/6 months @ 5 ppm
Response	30 seconds	30 seconds

Sensor Specifications: Carbon Monoxide

Model Number	**SEN-COM-1**
Typical Application	**Carbon Monoxide Monitoring or Control**
Sensor: COM	
Element	Electrochemical Sensor
Range	0−150 ppm
Accuracy	± 3 ppm or 5% of reading, (whichever is greater)
Resolution	1 ppm

Appendix F

SEQUENCE OF OPERATION FOR LABORATORY/VIVARIUM APPLICATIONS

Overview

The Laboratory Airflow Control System (LACS) will control the airflow control valves in response to the greatest of three demands:

1. Temperature control
2. Fume hood demand
3. Multi-Parameter DCV (MpDCV) command from the FMS

The temperature controls and fume hood controls will operate independent of the FMS and shall override the MpDCV command when required to maintain comfort, space pressurization, and well-being.

The FMS will provide analog proportional MpDCV signals that correspond to the contaminant levels (TVOC, particles, CO2, etc.) sensed within the General Exhaust (GEX) duct probe(s) for each lab as indicated in Table 1 below.

The Aircuity system shall provide an MpDCV signal that corresponds to an Air Change per Hour (ACH) ventilation rate that is defined by the contaminant levels (TVOC, Particles, CO2, etc.) sensed within the Laboratory. These sensed parameters shall be measured against a supply air reference point that shares the same sensor set and is representative of the air being supplied to the space, typically at the Air Handling Unit, to provide a space-specific differential measurement. This differential measurement shall be converted to an MpDCV signal in ACH based on a prescribed control range for each contaminant type and sent to the LACS.

Reduction in Minimum Ventilation Setpoint, Air Changes per Hour (ACH)

When the GEX air contains a contaminant (e.g. TVOC, particles, CO2, etc.) concentration, as sensed by the FMS, that is below minimum setpoint (configured within the LACS) the minimum airflow setpoint within the LACS shall be reset to **[4]** ACH during occupied hours and **[2]** ACH during unoccupied hours. The actual lab ACH shall be dynamic and equal to the higher of the temperature control demand, the fume hood exhaust demand, and the MpDCV command from the FMS.

Increase in Air Changes per Hour (ACH)

When the GEX air contains a contaminant concentration, as sensed by the FMS that is above high setpoint (configured within the LACS) the minimum airflow setpoint within the LACS shall be reset to a maximum ACH of 18 during both occupied and unoccupied hours.

For GEX contaminant concentration levels that are between the low and high setpoints, the LACS shall correspondingly and proportionally increase the minimum airflow during both occupied and unoccupied hours.

Once the GEX air contains a contaminant concentration, as sensed by the FMS that is below setpoint (configured within the LACS) the minimum airflow setpoint within the LACS shall be reset as described above.

Table 1 – DCV Signal and Differential Contaminant Ranges:

DCV Signal (ACH)	0	18	Units
TVOCs – PID	0.1	1	ppm as isob
TVOCs – MOS	0.3	3	ppm as isob
CO2	300	3,000	ppm
Particles	500,000	5,000,000	pcf

[FOR VIVARIUM APPLICATIONS ONLY (WHERE A SEN-TVC-1&3 HAS BEEN PROVIDED), THE TVOC – PID SENSOR RANGE SHOULD BE CHANGED TO: 1–10 ppm as Ammonia]

Integration Methods & Failsafe Programming

The above sequence of operations assumes the pneumatic and electrical integrity of the FMS system is in good working order and is functioning as designed. However, there are instances where the FMS may produce invalid or no data (i.e. – during a scheduled sensor swap, when the systems are shut down, or upon a catastrophic system failure). To safely accommodate these scenarios, the following failsafe logic should be programmed into the BAS/LACS:

For installations where the FMS is integrated with the BAS/LACS via BACnet, the BAS/LACS shall not only read the present values of each BACnet point, but also the reliability property of each BACnet point.

While operating in any mode, in the event that the reliability property of a BACnet point generated by the FMS in any particular room(s) switches from a “Reliable” state to an “Unreliable” state, the BAS/LACS shall:

- Issue an alarm for those affected rooms, and
- Ignore any MpDCV value produced by the FMS for those affected room(s), and command the minimum air change rate in each affected room back to their code-prescribed minimum air change rate values

The LACS shall be allowed to resume normal operational control sequence only after the reliability properties of all associated BACnet point have switched back to a ‘reliable’ state.

For installations where the FMS is integrated with the BAS/LACS via hardwired analog control wiring, the specified control ranges shall be either 4-20mA, 1-5V, or 1-10V (forward or reverse acting).

With this approach, during any mode of operation, any analog signal read by the BAS/LACS of 0mA or 0V shall be interpreted as a system failure or a loss of communication with the FMS.

When this occurs, the BAS/LACS shall issue an alarm for those affected rooms and drive those same rooms to their code-prescribed minimum air change rate values until the associated analog signals return to their normal signal ranges.

For installations which utilized BOTH integration methods described above, both approaches for configuring failsafe values shall be utilized to ensure the safest possible sequence of operation and integration methods for all occupants of the rooms.

Appendix G

FOR APPLICATIONS USING THE EXHAUST FAN CONTROL APPLICATION MODULE ONLY!!!

Insert the following tables into Section 2.5-B.4 then delete this appendix.

Sensor Specifications: Total Volatile Organic Compounds

Model Number	**EFS-TVC-1&3**	
Technology	**MOS/Enhanced PID**	
Typical Application	**Combines the MOS and an enhanced version of the PID sensing technology into one single assembly that is designed for use in the monitoring of exhaust plenum Demand Based Control (DBC) of exhaust fans.**	
Sensor: TVOCs		
Technology	**MOS**	**PID**
Element	Metal Oxide Semiconductor (MOS)	Photoionization Detector (PID)-VOCs & other gases with ionization potentials <10.6eV
Range	**Calibrated Range:** 0−50 ppm (as Isobutylene) **Maximum Range:** 0−100 ppm (as Isobutylene)	**Calibrated Range:** 0−5 ppm (as Isobutylene) **Maximum Range:** 0−20 ppm (as Isobutylene)
Accuracy	± .5 ppm (as Isobutylene) or 25% of reading (whichever is greater)	± .2 ppm (as Isobutylene) or 2.5% of reading (whichever is greater)
Resolution	0.2 ppm	0.025 ppm
Drift Stability	± 15 ppm/6 months @ 50 ppm	± 2 ppm/6 months @ 5 ppm
Response	30 seconds	30 seconds

Appendix H

SEQUENCE OF OPERATION FOR EXHAUST FAN CONTROL APPLICATIONS

Disclaimer: *The below sequence of operations is a suggestion by Aircuity only. Final sequence of operations shall always be verified and approved by the project's licensed Professional Engineer of record and shall always be deemed appropriate by the Authority Having Jurisdiction.*

Overview

The Laboratory Exhaust Fan System (LEFS) will control the fan speed in response to the greatest of three demands:

1. Total Building Exhaust Flow from the BAS/LACS
2. LEFS Static Pressure Requirements
3. Total Volatile Organic Compound (TVOC) Contaminant Signal from the FMS (ppm as isobutylene)

The FMS shall sequentially sample each duct probe installed in the Laboratory Exhaust Fan System's (LEFS) plenum and route all air samples through the EFS-TVC-1&3 sensor found in the Sensor Suite (SST) in order to determine the absolute level of TVOCs present in the airstream which is to be exhausted.

The absolute contaminant values sensed within the LEFS's plenum shall be compared to the absolute contaminant values as sensed by a single supply air reference probe, which shall share the same sensor set as the probes which are sampling from the LEFS's plenum, and is also representative of the air being supplied to the lab spaces, which is ultimately being exhausted by the LEFS. This comparison is done to provide a plenum-specific, high-selected, differential measurement.

Reduction of Dilution Ratio (Low Dilution Mode)

At a rate of once every three minutes (or sooner), the FMS shall update the Exhaust Fan Control Application Module output signal(s) based on the calculated differential measurement signal. When the Exhaust Fan Control Application Module's output signal is below the chosen threshold value (typically 1 ppm as isobutylene – or as determined by the project's exhaust fan dispersion consultant), the speed of the exhaust fans shall be allowed to be reduced in order to achieve a total dilution ratio of **750:1**. This is what will be referred to as "Low-Dilution Mode".

While in this mode, using the BAS or other control system, the LEFS shall continue to respond to total building exhaust flow, pressurization, and effective stack height requirements, as well as manufacturer-specific mechanical equipment safeties and jurisdictional-specific life safety requirements & sequences as needed to help maintain a safe working environment within the occupied building areas and in the areas surrounding the LEFS outside of the building.

When the LEFS bypass dampers are closed or at minimum position, and the total quantity of air exhausted from the interior of the building may be reduced to the point where the total dilution ratio of the LEFS would drop below 750:1, then the LEFS shall open up its bypass air dampers to allow for more ambient air to be exhausted by the LEFS until the desired total dilution ratio of 750:1 is achieved and maintained.

When the LEFS bypass dampers are closed or at minimum position, and the total quantity of air exhausted from the interior of the building must be increased, then the LEFS shall increase fan speed to allow for more building air to be exhausted by the LEFS while simultaneously achieving a total dilution ratio of 750:1.

When the static pressure of the LEFS falls outside of acceptable setpoint range during low dilution operating mode, the exhaust static pressure setpoint shall be maintained by a combination of fan staging (if more than one fan is involved) and control of the speed of the fans to match the exhaust flow to the exhaust flow from the building.

Increase in Dilution Ratio (High Dilution Mode)

When the Exhaust Fan Control Application Module's output signal is at or above the chosen threshold value, the speed of the exhaust fans shall be increased to achieve a total dilution ratio of **3,000:1**. This is what will be referred to as "High-Dilution Mode".

While in this mode, using the BAS or other control system, the LEFS shall continue to respond to total building exhaust flow, pressurization, and effective stack height requirements, as well as manufacturer specific mechanical equipment safeties and jurisdictional specific life safety requirements & sequences as needed to help maintain a safe working environment within the occupied building areas and in the areas surrounding the LEFS outside of the building.

When the LEFS is commanded into this High Dilution Mode, the amount of air required to be exhausted from the building will likely remain unchanged, therefore, to increase the dilution ratio of the exhausted airstream, the LEFS shall modulate open its bypass dampers, increase fan speeds, and switch on any additional fans as required by the LEFS to maintain building exhaust air flow rates, effective plume heights, static pressure requirements, etc…

Once the LEFS enters this High Dilution mode, the LEFS shall remain in this mode of operation for a minimum of 15 minutes before being allowed to drop back into the Low Dilution Mode to both protect the sensors in the Sensor Suite, and to protect the LEFS and its various components from rapidly cycling between modes of operation.

After 15 minutes, if the exhaust air plenum is determined, as sensed the FMS, to contain a contaminant concentration, that is below the differential threshold value, the LEFS shall be allowed to enter the "Low Dilution Mode" as described above.

When the static pressure of the LEFS falls outside of acceptable setpoint range during high dilution operating mode, the exhaust static pressure setpoint shall be maintained by a combination of fan staging (if more than one fan is involved) and control of a bypass damper connected to the exhaust fan plenum to provide roof air into the plenum to compensate for a reduction in exhaust flow from the building.

Integration Methods & Failsafe Programming

The above sequence of operations assumes the pneumatic and electrical integrity of the FMS system is in good working order and is functioning as designed. However, there are instances where the FMS may produce invalid or no data (i.e. – during a scheduled sensor swap, when the systems are shut down, or upon a catastrophic system failure). To safely accommodate these scenarios, the following failsafe logic should be programmed into the BAS/LEFS:

For installations where the FMS is integrated with the BAS/EFS via BACnet, the BAS/LEFS shall not only read the present values of each BACnet point, but also the reliability property of each BACnet point.

While operating in any mode, in the event that the reliability property of any BACnet point generated by the FMS relating to the control of the LEFS switches from a "Reliable" state to an "Unreliable" state, the BAS/LEFS shall:

- Issue an alarm for the affected exhaust fan system(s), and
- Ignore any value produced by the FMS for the LEFS, and command the LEFS into the High Dilution Mode control sequence for each affected LEFS

The LEFS shall be allowed to resume normal operational control sequences only after the reliability properties of all associated BACnet points have switched back to a 'reliable' state.

For installations where the FMS is integrated with the BAS/EFS via hardwired analog control signals, the specified control ranges shall be either 4-20mA, 1-5V, or 1-10V (forward or reverse acting).

With any of those approaches, during any mode of operation, any analog signal read by the BAS/LEFS of 0mA or 0V shall be interpreted as a loss of communication or failure of the FMS.

When this occurs, the BAS/LEFS shall issue an alarm for those affected exhaust fan system(s) and command the LEFS into the High Dilution Mode control sequence for each affected LEFS until the control signals are back within their normal specified ranges.

Appendix I

FOR OPERATING ROOM CLEAN STANDBY APPLICATIONS ONLY!!!

Insert the following tables into Section 2.5-B.4 then delete this appendix.

Sensor Specifications: Total Volatile Organic Compounds

Model Number	**SEN-TVC-1&2**	
Technology	**MOS/ PID**	
Typical Application	**Combines the MOS and PID sensing technology into a single assembly, while supporting the individual sensing capabilities of each. This configuration is recommended for monitoring only or for control of critical spaces such as research labs.**	
Sensor: TVOCs		
Technology	**MOS**	**PID**
Element	Metal Oxide Semiconductor (MOS)	Photoionization Detector (PID)-VOCs & other gases with ionization potentials <10.6eV
Range	**Calibrated Range:** 0−50 ppm (as Isobutylene) **Maximum Range:** 0−100 ppm (as Isobutylene)	**Calibrated Range:** 0−5 ppm (as Isobutylene) **Maximum Range:** 0−20 ppm (as Isobutylene)
Accuracy	± .5 ppm (as Isobutylene) or 25% of reading (whichever is greater)	± .2 ppm (as Isobutylene) or 2.5% of reading (whichever is greater)
Resolution	0.2 ppm	0.025 ppm
Drift Stability	± 15 ppm/6 months @ 50 ppm	± 2 ppm/6 months @ 5 ppm
Response	30 seconds	30 seconds

Sensor Specifications: Carbon Dioxide / Carbon Dioxide & Dewpoint Temperature

Model Number	SEN-CO2-2A	SEN-CO2-2B	SEN-CO2-3	SEN-C2D-3
Typical Application	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based Demand Controlled Ventilation (DCV) or Monitoring**	**CO2 Based DCV or Monitoring; Dewpoint Temp, Relative Humidity*, Enthalpy*, Monitoring or Control**
Sensor: Carbon Dioxide (CO2)				
Element	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor	Dual Wavelength, Non-Dispersive Infrared Sensor
Range	0−3000 ppm	0−3000 ppm	0−2000 ppm	0−3000 ppm
Accuracy	± 60 ppm up to 1000 ppm	± 75 ppm up to 1000 ppm	± 45 ppm up to 1000 ppm	± 45 ppm up to 1000 ppm
Repeatability	± 5 ppm	± 9 ppm	± 2 ppm	± 3 ppm
Resolution	3 ppm	3 ppm	2 ppm	3 ppm
Response	25 seconds	10 seconds	10 seconds	10 seconds
Sensor: Dewpoint Temp (DPT)				
Element				Dual Wavelength, Non-Dispersive Infrared Sensor
Range				-58 to ambient DPT Deg F or 122 Deg F, whichever is less
Accuracy				Dewpoint: ± .9 Deg F (± .5 Deg C) from 20 to 65 Deg F DPT RH: @ 65°F and ± .5°F ± 3% RH @10−60% RH ± 4% RH @ 61−90% RH
Response				10 seconds

*Select specific CO2 Sensor and delete the remainders from the table.

Sensor Specifications: Airborne Particulates

Model Number	SEN-PAR-2
Typical Application	**Particulate Monitoring or Control: Designed for use in Vivariums, Healthcare Facilities, Clean Rooms and other Applications**
Sensor: Airborne Particulates - Small Particles PM2.5	Dual Channel
Element	Optical Particle Counter
Range	PM2.5: 0.3−2.5μm, 0.5−2.5μm, 0.3−2.5 μm
Accuracy	± 25% of reading
Concentration Range	100−10,000,000 particles pcf
Response	30 seconds

Sensor Specifications: Carbon Monoxide

Model Number	**SEN-COM-1**
Typical Application	**Carbon Monoxide Monitoring or Control**
Sensor: COM	
Element	Electrochemical Sensor
Range	0−150 ppm
Accuracy	± 3 ppm or 5% of reading, (whichever is greater)
Resolution	1 ppm

Appendix J

SEQUENCE OF OPERATION FOR OPERATING ROOM CLEAN STANDBY APPLICATIONS

***Disclaimer:** The below sequence of operations is a suggestion by Aircuity only. Final sequence of operations shall always be verified and approved by the project's licensed Professional Engineer of record and shall always be deemed appropriate by the Authority Having Jurisdiction.*

Overview

During all time periods, regardless of occupancy status, the Building Automation System (BAS) or Operating Room Control System (ORCS) shall be responsible for providing control of the air flow within each individual operating room to the greatest of multiple airflow demands:

1. Temperature & Humidity Control
2. Pressurization Control
3. Minimum Air Change Rate Control
4. **[Insert other project specific controls which impact airflow control decisions here]**
5. Multi-Parameter DCV (MpDCV) command from the Aircuity System (FMS)

All operating room controls shall operate independent of the FMS and shall override the Multi-Parameter Demand Controlled Ventilation (MpDCV) signal produced by the FMS (regardless of room occupancy status) when required to maintain comfort, space pressurization, and the safety & well-being of all Operating Room occupants.

The FMS will systematically extract air samples from the operating room's General Exhaust (GEX) or Return Air (RA) ductwork in order to sense the contaminant levels (TVOCs, particulates, CO2, etc.) extracted from within each operating room's GEX and/or RA ductwork. The FMS will continue operating until the FMS is disabled.

All air samples extracted from each operating room shall have their sensed contaminant levels compared to a 'clean' supply air reference sample that shares the same sensor set and is representative of the air being supplied to the space (final installation location for all SA references must be after final stage of supply air filtration) in order to provide a true measurement of the rise of each contaminant within each operating room's environment.

Each differential measurement shall then be converted to an MpDCV signal and made available to the BAS/ORCS in units of ACH and/or CFM based on a prescribed control range for each contaminant type as indicated in Table 1 below. In the event a single operating room contains more than one sensing location, the FMS shall generate its MpDCV signal based off whichever sensing location within said operating room is determined to have the highest level of contaminants.

Reduction of Minimum Air Change Rate during Occupied Hours

During occupied time periods (as determined by occupancy sensor or schedule – by others), unless specifically granted permission by the Authority Having Jurisdiction, reducing the minimum air change rate within an occupied operating room shall not be allowed. The FMS shall continue to operate (drawing air samples, producing data, etc…), however, its MpDCV signals shall not be allowed to impact the minimum ventilation rate during occupied time periods.

Reduction of Minimum Air Change Rate during Unoccupied Hours ("Clean Standby Mode")

During unoccupied time periods (as determined by occupancy sensor or schedule – by others), the minimum air change rate within each operating room shall only be allowed to be reduced provided that the pressure relationship to the adjoining spaces are maintained while that space is in unoccupied mode, and that the minimum number of required air changes required by the code is reestablished anytime the space becomes occupied.

During "Clean Standby Mode", the FMS shall continue to function as described in the "Overview" section above – producing MpDCV signals in proportion to the rise of contaminants within each operating room.

During “Clean Standby Mode” the BAS/ORCS shall adjust its minimum Air Change Rate setpoint during clean standby mode for each operating room down to **[XX]** ACH (adjustable) as long as the room is unoccupied.

When the GEX or RA of a particular operating room contains a sensed contaminant concentration, as determined by the FMS, which results in an MpDCV signal whose magnitude exceeds all other airflow control demands for that particular room at that time, the BAS or ORCS shall dynamically increase and decrease that operating room’s air change rate in response to the recommended MpDCV air change rate value (produced by the FMS) until the magnitude of the MpDCV signal drops back below that of all other airflow control demands for that particular room at that time.

Table 1 – DCV Signal and Differential Contaminant Ranges:

DCV Signal (ACH)	0	18	Units
TVOCs – PID	0.1	1	ppm as isob
TVOCs – MOS	0.3	3	ppm as isob
CO2	300	3,000	ppm
Particles (PM2.5)	500,000	5,000,000	pcf

Integration Methods & Failsafe Programming

The above sequence of operations assumes the pneumatic and electrical integrity of the FMS system is in good working order and is functioning as designed. However, there are instances where the FMS may produce invalid or no data (i.e. – during a scheduled sensor swap, when the systems are shut down, or upon a catastrophic system failure). To safely accommodate these scenarios, the following failsafe logic should be programmed into the BAS/ORCS:

For installations where the FMS is integrated with the BAS/ORCS via BACnet, the BAS/ORCS shall not only monitor the present values of each BACnet point, but also the reliability property of each BACnet point.

During “Clean Standby Mode”, in the event that the reliability property of a BACnet point generated by the FMS in any particular room(s) switches from a “Reliable” state to an “Unreliable” state, the BAS/ORCS shall:

- Issue an alarm for those affected rooms, and
- Ignore any MpDCV value produced by the FMS for those affected operating room(s), and command the minimum air change rate in each affected operating room back to their code-prescribed minimum air change rate values

The ORCS shall be allowed to resume normal operational control sequences only after the reliability properties of all associated BACnet points have switched back to a ‘reliable’ state.

For installations where the FMS is integrated with the BAS/ORCS via hardwired analog control wiring, the specified control ranges shall be either 4-20mA, 1-5V, or 1-10V (forward or reverse acting).

With this approach, during “Clean Standby Mode”, any analog signal read by the BAS/ORCS of 0mA or 0V shall be interpreted as a system failure or a loss of communication with the FMS.

When this occurs, the BAS/ORCS shall issue an alarm for those affected rooms and drive those same rooms to their code-prescribed minimum air change rate values until the associated analog signals return to their normal signal ranges.

For installations which utilized BOTH integration methods described above, both approaches for configuring failsafe values shall be utilized to ensure the safest possible sequence of operation and integration methods for all occupants of the operating rooms.

Appendix K

SEQUENCE OF OPERATION FOR MULTI-ZONE CO2 BASED DCV WITH PRIMARY FLOW & OUTSIDE AIR FLOW RESET

The main goal of this approach is to implement a two-part Demand Controlled Ventilation (DCV) control scheme which is capable of intelligently adjusting the room/zone-level primary air flowrates for all zones monitored by the Aircuity System ('Critical Zones') based on the sensed rise in CO2 levels within those zones while simultaneously adjusting the AHU's Outside Air (OA) damper position in response to the greater of the following two calculated CO2 rise components at any point in time:

1. The rise in CO2 concentration sensed at the AHU's main Return Air (RA) inlet
2. The Critical Zone with the highest normalized CO2 rise (each critical zone's sensed CO2 rise value is normalized to the same CO2 range as the AHU's RA component)

This approach will ensure the AHU's Outside Air damper position is always at the lowest opening percentage necessary to satisfy the ventilation requirements of all monitored zones while simultaneously ensuring the average CO2 concentrations for all spaces connected to that AHU (whether they are monitored or not) are able to stay below a predetermined maximum rise value.

Configuring Proportional Zone-Level DCV Signal:

DCV is most effective when applied to areas that are more densely populated or are subject to high variability in occupancy. This approach is generally not applied to areas that are either consistently occupied or have very low occupancy densities (i.e. corridors, closets, etc…) because the demand for ventilation in these spaces is relatively low and will not vary by much throughout the day. Areas like these that are often overventilated tend to return "unused" air back to the air handler. Any "unused" air may then be recirculated for the purposes of ventilating other spaces which are fed by the same AHU.

The Aircuity System shall be configured to provide a DCV signal to each monitored zone's VAV box controller in response to the levels of CO2 as sensed by the Aircuity System. The DCV signal for each zone will be proportional to the level of CO2 rise (compared to an Outside Air reference) as it increases and decreases throughout the day.

Determining the Minimum CO2-based DCV Signal Range Values

For each monitored zone, a sensed CO2 rise of 500ppm (adjustable) will equate to a DCV signal of 0% - meaning no additional ventilation is required above the minimum specified ventilation airflow rate.

[Alternate] If each zone will feature a unique lower CO2 limit, specify each zone's lower limit for the CO2 control range here. Sensed CO2 rise values at or below these specified values shall result in no increase in ventilation above the minimum specified ventilation airflow rate.

Determining the Maximum CO2-based DCV Signal Range Values

For each zone to be configured with its own DCV signal, the maximum expected CO2 rise must be determined for each space. Each Critical Zone's maximum anticipated CO2 rise shall be equivalent to the upper limit of the CO2 control range and shall be calculated using Equations 1, 2, and 3 later in this sequence.

For each space, this calculated value shall represent the upper control range limit of the CO2 based DCV signal. Sensed CO2 rise values at or above these specified values shall drive the HVAC system to provide the maximum specified ventilation airflow rate for each space.

Controlling Outside Air Damper Position:

The Outside Air intake flow, which is ultimately controlled by the AHU's Outside Air damper position, shall be modulated by two independent PI control loops in order to determine which of the following two IAQ based demands are greatest at any point in time:

1. The least satisfied of all monitored Critical Zones, or…
2. The AHU's Return Air CO2 concentration

The feedback error of the least satisfied of all monitored Critical Zones is used to gauge the HVAC system's ability, at its current Outside Air Fraction, to supply enough ventilation air to those critical/monitored spaces. The Outside Air Fraction may be simply defined as the ratio of the outdoor-air intake to the total supply airflow rate. The feedback error of the sensed CO2 level in the AHU's Return Air main duct is used to gauge the HVAC system's approximate ability, at its current Outside Air Fraction, to supply enough ventilation air to those spaces which are not monitored by the Aircuity system, but are also affected by the changes in Outside Air Damper position.

This innovative, two-pronged approach helps ensure Critical Zones (which are actively monitored by the Aircuity System) are able to operate within their specified CO2 setpoint ranges with the additional benefit of being part of the decision to increase or decrease the AHU's Outside Air Fraction. This is important should one or more critical zones experience a sharp increase in CO2 which, at the current Outside Air Fraction, would otherwise take far too long to reduce below the upper CO2 range limit. Also, with the inclusion of a probe installed in the main Return Air duct, this approach also helps ensure the average ventilation needs of all unmonitored zones are both able to be met and influence the decision to increase or decrease the AHU's Outside Air Fraction.

The BAS shall utilize a PI (proportional-integral) control loop to control the Outside Air damper position (in conjunction with other equipment safeties or life safety control strategies).

Sequence:

1. At a set interval of once a minute, the BAS shall read and normalize all differential CO2 values from the Aircuity System (see **Normalizing CO2 Values** below) in order to determine which critical zone has the greatest need for additional ventilation at that time.
2. At the same sampling rate (once a minute), the BAS shall read the calculated differential CO2 value from the Aircuity System's AHU Return Air probe.
3. The BAS shall then high select between the values calculated in Steps 1 and 2 above and feed the resulting error term (after a common comparison to the Return Air setpoint value) into a PI control loop (see **Control Loop Configuration** section below for more information) for the purposes of controlling the Outside Air Damper.
4. In addition, the output of this control scheme must be high-selected with Outside Air damper commands such as temperature control, economizer control, and other AHU safety controls.

Using this approach, the Outside Air intake flow will continuously modulate to satisfy the building ventilation requirements as they increase or decrease throughout the day.

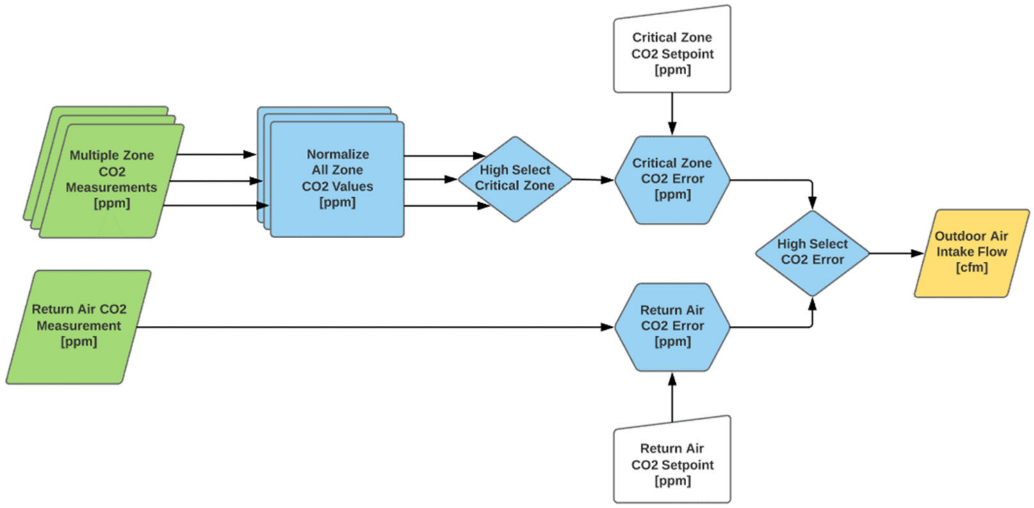

Figure 1: Outside Air Intake Control Flowchart

PI Control Loop Configuration:

The BAS can control the AHU's Outside Air damper by using a traditional PI control strategy. Because of the presence of an integral term, which is influenced by both the magnitude and duration of past error values, additional consideration must be given to the following:

An anti-windup strategy (such as signal clamping) should be utilized to help reduce the amount of time to achieve steady state control after a significant event such as a system start-up, setpoint change, or occupancy surge. Events such as these trigger the need for an anti-windup strategy since the Outside Air damper position setpoint may accumulate excessive integral feedback error terms until the system has been given time to stabilize.

Because the Aircuity system utilizes a sampling scheme with cycle times that may be on the order of 10 to 15 minutes, it is important that the integral-time settings of the control loop be configured to accommodate such a relatively slow process. A general rule of thumb to use when setting the integral time constant is to select an integral time constant value that is 4-5 times greater than the overall Aircuity System cycle time.

Determining the Maximum CO2 Rise for each Critical Zone:

For every space, the greatest amount of CO2 generation occurs when those zones are at maximum occupancy, with all occupants functioning at their anticipated activity levels, and the HVAC system operating at its minimum airflow rate.

Since the zone population and activity levels are values which may be read from a table, begin by solving for each zone's minimum outdoor airflow (V_{ot}) by using Equations 1 and 2 below:

First, solve for the minimum airflow required to be delivered to each zone's 'Breathing Zone' (V_{bz}):

$$V_{bz} = (R_p * P_z) + (R_a * A_z) \qquad \textbf{(Eq. 1)}$$

Where:

V_{bz}	=	Outdoor Air Flowrate required in the 'Breathing Zone' of the zone	[CFM]
R_p	=	Outdoor Air Flowrate per person (per ASHRAE 62.1-2016 Table 6.2.2.1)	[CFM]
P_z	=	Zone population, the number of people in the ventilation zone during use	[#]
R_a	=	Outdoor Air Flowrate required per unit area (per ASHRAE 62.1-2016 Table 6.2.2.1)	[CFM]
A_z	=	Zone floor area (net occupiable space)	[ft²]

Then, accounting for inefficiencies in the zone's air distribution, use the values listed for E_z in Table 6.2.2.2 of ASHRAE 62.1-2016 to solve for each zone's minimum outdoor airflow (V_{oz}):

$$V_{oz} = \frac{V_{bz}}{E_z} \qquad \textbf{(Eq. 2)}$$

Where:

V_{bz}	=	Minimum Outdoor Air Flowrate required to be delivered to the zone	[CFM]
E_z	=	Zone Air Distribution Effectiveness (per ASHRAE 62.1-2016 Table 6.2.2.2)	[-]

Finally, for each zone, determine the zone target max CO2 rise (C_s-C_o) by using the equation below:

$$V_{oz} = \frac{N*P*1{,}000{,}000}{(C_s - C_o)} \quad \text{or} \quad (C_s - C_o) = \frac{(N*P*1{,}000{,}000)}{V_{oz}} \qquad \textbf{(Eq. 3)}$$

Where:

C_s	=	CO_2 concentration in the space	[ppm]
C_o	=	CO_2 concentration in outdoor air	[ppm]
N	=	CO_2 generation rate per person (see ASHRAE 62.1-2016 INFORMATIVE APPENDIX D)	[CFM]
P	=	Zone Population	[-]
V_{oz}	=	Zone's minimum outdoor airflow	[CFM]

Normalizing CO2 Values:

Normalizing the CO2 rise values from the critical zones is a necessary step to ensure all critical zones are weighted equally to one another, as well as to the Return Air component of this sequence. This approach also makes it much easier to determine which may be in greater need of additional ventilation:

1. The least satisfied of all Critical Zones, or…
2. All other unmonitored zones

For each zone, determined the normalized CO2 value using the equation below:

$$\widehat{CZ_{CO2}} = \frac{CZ_{CO2}}{(CZ_{CO2})_{max}} \times RASP_{CO_2} \qquad \textbf{(Eq. 4)}$$

Where:

$\boldsymbol{\widehat{CZ_{CO2}}}$	=	Normalized critical zone CO2 value	[ppm]
CZ$_{CO2}$	=	CO2 rise measured within the Critical Zone	[ppm]
CZ$_{CO2max}$	=	Maximum Expected CO2 rise within the Critical Zone	[ppm]
RASP$_{CO2}$	=	Return Air CO2 rise setpoint	[ppm]

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