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**SECTION 23 08 00 – HVAC COMMISSIONING REQUIREMENTS**

PART 1 – GENERAL

* 1. RELATED DOCUMENTS

		1. Drawings and general provisions of the Contract, including General and Supplementary Conditions and other Division 01 Specification Sections, apply to this section.
		2. Where conflicts exist between the specification and/or drawings, the more stringent requirement shall apply.
		3. Refer to Sections in Division 22,23,26 and 27 for general requirements pertaining to mechanical, plumbing, electrical and communications work.
		4. Refer to current Caltech standards on-line for latest versions for the project. [https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards) Included appendices are for reference only.
	2. SUMMARY
		1. This section includes commissioning process requirements for HVAC&R systems, assemblies, and equipment.
		2. Related Sections:
			1. Division 01 Section "General Commissioning Requirements" for general commissioning process requirements.
	3. DESCRIPTION

		1. Refer to Division 01, the section 19113 "General Commissioning Requirements" for the description of commissioning.
	4. DEFINITIONS
		1. Refer to Division 01, the section 19113 "General Commissioning Requirements" for definitions.
	5. SUBMITTALS
		1. Refer to Division 01, the section 19113 "General Commissioning Requirements" for CxA’s role.
		2. Refer to Division 01 Section “Submittals” for specific requirements.
		3. Control drawing submittal review for compliance to Caltech standards.
			1. The control drawings shall have a key to all abbreviations.
			2. The control drawings shall contain graphic schematic depictions of the systems and each component.
			3. The schematics will include the system and component layout of any equipment that the control system monitors, enables, or controls, even if the equipment is primarily controlled by packaged or integral controls.
			4. The control drawings shall provide a full points list with at least the following included for each point:
				1. Controlled system
				2. Point abbreviation
				3. Point description
				4. Display unit
				5. Control point or set point (Yes / No)
				6. Monitoring point (Yes / No)
				7. Intermediate point (Yes / No)
				8. Calculated point (Yes / No)
		4. Submit draft of system verification form, functional performance test checklist and proposed procedures for control system developed with controls contractor to AOR/MEOR and Owner for review and acceptance.
	6. QUALITY ASSURANCE

		1. Test Equipment Calibration Requirements: Contractors will comply with test manufacturer’s calibration procedures and intervals. Recalibrate test instruments immediately after instruments have been repaired resulting from being dropped or damaged. Affix calibration tags to test instruments. Furnish calibration records to CxA upon request.
	7. COORDINATION
		1. Refer to Division 01 Section “General Commissioning Requirements” for requirements pertaining to coordination during the commissioning process.

PART 2 – PRODUCTS

* 1. QUALIFICATIONS
		1. Dedicated commissioning personnel for the verification work, including a Certified Commissioning Professional (CCP) as accredited by the Building Commissioning Certification Board and by ANSI to the ANSI/ISO/IEC 17024:2012 standard.
		2. Compliance with the following standards, guidelines and best practices:
			1. ASHRAE Standard 202-2018 The Commissioning Process for Buildings and Systems.
			2. ASHRAE Guideline 0-2009 The Commissioning Process.
			3. ASHRAE Guideline 0.2-2015 -- Commissioning Process for Existing Systems and Assemblies.
			4. ASHRAE Standard 230(P) The Commissioning Process for Existing Buildings.
			5. The Building Commissioning Handbook (Bjornskov, Stum, Third ed. 2017).
			6. Building Commissioning Association’s (BCA) New Construction Building Commissioning Best Practices (February 2016).
			7. Building Commissioning Association’s (BCA) Existing Building Commissioning Best Practices (September 2019).
	2. TEST EQUIPMENT
		1. All standard testing equipment required to perform startup, initial checkout, and assist in functional performance testing shall be provided by the Contractor for the equipment being tested. For example, the mechanical contractor of Division 23 shall ultimately be responsible for all standard testing equipment for the HVAC&R system and controls system in Division 23, except for equipment specific to and used by TAB in their commissioning responsibilities.
		2. Special equipment, tools and instruments (specific to a piece of equipment and only available from vendor) required for testing shall be included in the base bid price to the Owner and left on site, except for stand-alone data logging equipment that may be used by the CxA.
		3. Proprietary test equipment and software required by any equipment manufacturer for programming and/or start-up, whether specified or not, shall be provided by the manufacturer of the equipment. Manufacturer shall provide the test equipment, demonstrate its use, and assist in the commissioning process as needed. Proprietary test equipment (and software) shall become the property of the Owner upon completion of the commissioning process.
		4. Data logging equipment and software required to test equipment will be provided by the CxA but shall not become the property of the Owner.
		5. All testing equipment shall be of sufficient quality and accuracy to test and/or measure system performance with the tolerances specified in the Specifications. If not otherwise noted, the following minimum requirements apply: Temperature sensors and digital thermometers shall have a certified calibration within the past year to an accuracy of 0.5°F and a resolution of + or - 0.1°F. Pressure sensors shall have an accuracy of + or - 2.0% of the value range being measured (not full range of meter) and have been calibrated within the last year.
	3. GENERAL DOCUMENTATION REQUIREMENTS
		1. With assistance from the installing contractors, the CxA will prepare Pre-Functional Checklists for all commissioned components, equipment, and systems
		2. Red-lined Drawings:
			1. The contractor will verify all equipment, systems, instrumentation, wiring, and components are shown correctly on red-lined drawings.
			2. Preliminary red-lined drawings must be made available to the Commissioning Team for use prior to the start of Functional Performance Testing.
			3. Changes, because of Functional Testing, must be incorporated into the final as-built drawings, which will be created from the red-lined drawings.
			4. The contracted party, as defined in the Contract Documents will create the as-built drawings.
		3. Operation and Maintenance Data:
			1. Contractor will provide a copy of O&M literature as specified in Division 01 of each submittal acceptance for use during the commissioning process for all commissioned equipment and systems.
			2. The CxA will review the O&M literature once for conformance to project requirements.
			3. The CxA will receive a copy of the final approved O&M literature once corrections have been made by the Contractor.
		4. Demonstration and Training:
			1. Contractor will provide demonstration and training as required by the specifications.
			2. A complete training plan and schedule must be submitted by the contractor to the CxA in accordance with Division 01 requirements prior to training for review.
			3. The CxA shall be notified at least 48 hours in advance of scheduled tests so that testing may be observed by the CxA and Owner's representative. A copy of the test record shall be provided to the CxA, Owner, and Architect.
			4. Engage a Factory-authorized service representative to train Owner's maintenance personnel to adjust, operate, and maintain specific equipment.
			5. Train Owner's maintenance personnel on procedures and schedules for starting and stopping, trouble shooting, servicing, and maintaining equipment.
			6. Review data in O&M Manuals.
		5. Systems manual requirements:
			1. The Systems Manual is intended to be a usable information resource containing all of the information related to the systems, assemblies, and Commissioning Process in one place with indexes and cross references.
			2. The GC shall include final approved versions of the following information for the Systems Manual:
				1. As-Built System Schematics
				2. Verified Record Drawings
				3. Test Results (not otherwise included in Cx Record)
				4. Periodic Maintenance Information for computer maintenance management system
				5. Recommendations for recalibration frequency of sensors and actuators
				6. A list of contractors, subcontractors, suppliers, architects, and engineers involved in the project along with their contact information
				7. Training Records, Information on training provided, attendees list, and any on-going training
			3. This information shall be organized and arranged by building system, such as fire alarm, chilled water, heating hot water, etc.
			4. Information should be provided in an electronic version to the extent possible. Legible, scanned images are acceptable for non-electronic documentation to facilitate this deliverable.
	4. CONTRACTOR'S RESPONSIBILITIES
		1. Mechanical, Controls and TAB Contractors. The commissioning responsibilities applicable to each of the mechanical, controls and TAB contractors of Division 23 are as follows (all references apply to commissioned equipment only):
			1. Assist with commissioning tests at the direction of the CxA.
			2. Attend construction phase controls coordination meetings.
			3. Attend testing, adjusting, and balancing review and coordination meetings.
			4. Participate in HVAC&R systems, assemblies, equipment, and component maintenance orientation and inspection as directed by the CxA.
			5. Provide information requested by the CxA for final commissioning documentation.
			6. Include requirements for submittal data, operation and maintenance data, and training in each purchase order or sub-contract written.
			7. Prepare preliminary schedule for Mechanical system orientations and inspections, operation and maintenance manual submissions, training sessions, pipe and duct system testing, flushing and cleaning, equipment start-up, testing and balancing and task completion for owner. Distribute preliminary schedule to commissioning team members.
			8. Update schedule as required throughout the construction period.
			9. During the startup and initial checkout process, execute the related portions of the pre-functional checklists for all commissioned equipment.
			10. Assist the CxA in all verification and functional performance tests.
			11. Provide measuring instruments and logging devices to record test data and provide data acquisition equipment to record data for the complete range of testing for the required test period.
			12. Gather operation and maintenance literature on all HVAC&R equipment including all fans, air handling units, ductwork, dampers, terminals, and all other equipment furnished under applicable Division as required by the specifications.
			13. Coordinate with the CxA to provide (48) hour advance notice so that the witnessing of equipment and system start-up and testing can begin.
			14. Notify the CxA a minimum of (2) weeks in advance of the time for start of the testing and balancing work. Attend the initial TAB meeting for review of the official testing and balancing procedures.
			15. Participate in, and schedule vendors and contractors to participate in the training sessions.
			16. Provide written notification to the CM/GC and CxA Authority that the following work has been completed in accordance with the contract documents, and that the equipment, systems, and sub-system are operating as required.
		2. Fire stopping in the fire rated construction, including fire and smoke damper installation, caulking, gasketing and sealing of smoke barriers.
		3. Fire detection and smoke detection devices furnished under other divisions of the specification.
		4. The equipment supplier shall document the performance of his equipment.
			1. Provide a complete set of red-lined drawings to the CxA prior to the start of Functional Performance Testing.
		5. Test, Adjust and Balance Contractor
			1. Attend initial commissioning coordination meeting scheduled by the Commissioning Authority.
			2. Submit the site-specific testing and balancing plan to the CxA and AE for review and acceptance.
			3. Attend the testing and balancing review meeting scheduled by the CxA. Be prepared to discuss the procedures that shall be followed in testing, adjusting, and balancing the HVAC&R system.
			4. At the completion of the testing and balancing work, and the submittal of the final testing and balancing report, notify the HVAC&R contractor and the CM/GC.
			5. Participate in verification of the testing and balancing report, which will consist of repeating measurements contained in the testing and balancing reports. Assist in diagnostic purposes when directed.
			6. Provide training of the Owner’s operating staff using expert qualified personnel, as specified and video record training. Video recording of the training to be provided to the owner.
		6. Equipment Suppliers
			1. Provide all requested submittal data, including detailed start-up procedures and specific responsibilities of the Owner, to keep warranties in force.
			2. Assist in equipment testing per agreements with contractors.
			3. Provide information requested by CxA regarding equipment sequence of operation and testing procedures.
			4. Refer to Division 01 Section “General Commissioning Requirements” for additional contractor responsibilities.
	5. OWNER’S RESPONSIBILITIES
		1. Refer to Division 01 Section “General Commissioning Requirements” for Owner’s Responsibilities.
	6. DESIGN PROFESSIONAL'S RESPONSIBILITIES

		1. Refer to Division 01 Section “General Commissioning Requirements” for Design Professional’s Responsibilities.
	7. CxA'S RESPONSIBILITIES

		1. Refer to Division 01 Section “General Commissioning Requirements” for CxA’s Responsibilities.
	8. TESTING PREPARATION
		1. Certify in writing to the CxA that HVAC&R systems, subsystems, and equipment have been installed, calibrated, and started and are operating according to the Contract Documents.
		2. Certify in writing to the CxA that HVAC&R instrumentation and control systems have been completed and calibrated, that they are operating according to the Contract Documents, and that pretest set points have been recorded.
		3. Certify in writing that testing, adjusting, and balancing procedures have been completed and that testing, adjusting, and balancing reports have been submitted, discrepancies corrected, and corrective work approved.
		4. Place systems, subsystems, and equipment into operating mode to be tested (e.g., normal shutdown, normal auto position, normal manual position, unoccupied cycle, emergency power, and alarm conditions).
		5. Inspect and verify the position of each device and interlock identified on checklists.
		6. Check safety cutouts, alarms, and interlocks with smoke control and life-safety systems during each mode of operation.
		7. Testing Instrumentation: Install measuring instruments and logging devices to record test data as directed by the CxA.
	9. TESTING, ADJUSTING AND BALANCING VERIFICATION
		1. Prior to performance of Testing, Adjusting and Balancing work, provide copies of reports, sample forms, checklists, and certificates to the CxA.
		2. Notify the CxA at least ten (10) days in advance of testing and balancing Work and provide access for the CxA to witness testing and balancing Work.
		3. Provide technicians, instrumentation, and tools to verify testing and balancing of HVAC&R systems at the direction of the CxA.
			1. The CxA will notify testing and balancing subcontractor ten (10) days in advance of the date of field verification. Notice will not include data points to be verified.
			2. The testing and balancing subcontractor shall use the same instruments (by model and serial number) that were used when original data were collected.
			3. Failure of an item includes, other than sound, a deviation of more than 10 percent. Failure of more than 10 percent of selected items shall result in rejection of final testing, adjusting, and balancing report. For sound pressure readings, a deviation of 3 dB shall result in rejection of final testing. Variations in background noise must be considered.
			4. Remedy the deficiency and notify the CxA so verification of failed portions can be performed.
	10. GENERAL TESTING REQUIREMENTS
		1. Provide technicians, instrumentation, and tools to assist with commissioning test at the direction of the CxA.
		2. Scope of HVAC&R testing shall include entire HVAC&R installation, from central equipment for heat generation and refrigeration through distribution systems to each conditioned space. Testing shall include measuring capacities and effectiveness of operational and control functions.
		3. Test all operating modes, interlocks, control responses, and responses to abnormal or emergency conditions, and verify proper response of building automation system controllers and sensors.
		4. The CxA along with the HVAC&R contractor, testing and balancing Subcontractor, and HVAC&R Instrumentation and Control Subcontractor shall prepare detailed testing plans, procedures, and checklists for HVAC&R systems, subsystems, and equipment.
		5. Tests will be performed using design conditions whenever possible.
		6. Simulated conditions may need to be imposed using an artificial load when it is not practical to test under design conditions. Before simulating conditions, calibrate testing instruments. Provide equipment to simulate loads. Set simulated conditions as directed by the CxA and document simulated conditions and methods of simulation. After tests, return settings to normal operating conditions.
		7. The CxA may direct that set points be altered when simulating conditions is not practical.
		8. The CxA may direct that sensor values be altered with a signal generator when design or simulating conditions and altering set points are not practical.
		9. If tests cannot be completed because of a deficiency outside the scope of the HVAC&R system, document the deficiency and report it to the Owner. After deficiencies are resolved, reschedule tests.
		10. If the testing plan indicates specific seasonal testing, complete appropriate initial performance tests and documentation and schedule seasonal tests.
	11. HVAC&R SYSTEMS, SUBSYSTEMS, AND EQUIPMENT TESTING PROCEDURES
		1. Equipment Testing and Acceptance Procedures: Testing requirements are specified in individual Division 23 sections. Provide submittals, test data, inspector record, and certifications to the CxA.
		2. HVAC&R Instrumentation and Control System Testing: Field testing plans and testing requirements are specified in Division 23 Sections "Instrumentation and Control for HVAC" and "Sequence of Operations for HVAC Controls." Assist the CxA with preparation of testing plans.
		3. Pipe system cleaning, flushing, hydrostatic tests, and chemical treatment: Test requirements are specified in Division 23 piping Sections. HVAC&R Contractor shall prepare a pipe system cleaning, flushing, and hydrostatic testing plan. Provide cleaning, flushing, testing, and treating plan and final reports to the CxA. Plan shall include the following:
			1. Sequence of testing and testing procedures for each section of pipe to be tested, identified by pipe zone or sector identification marker. Markers shall be keyed to Drawings for each pipe sector, showing the physical location of each designated pipe test section. Drawings keyed to pipe zones or sectors shall be formatted to allow each section of piping to be physically located and identified when referred to in pipe system cleaning, flushing, hydrostatic testing, and chemical treatment plan.
			2. Description of equipment for flushing operations.
			3. Minimum flushing water velocity.
			4. Tracking checklist for managing and ensuring that all pipe sections have been cleaned, flushed, hydrostatically tested, and chemically treated.
		4. Refrigeration System Testing: Provide technicians, instrumentation, tools, and equipment to test performance of chillers, cooling towers, refrigerant compressors and condensers, heat pumps, and other refrigeration systems. The CxA shall determine the sequence of testing and testing procedures for each equipment item and pipe section to be tested.
		5. HVAC&R Distribution System Testing: Provide technicians, instrumentation, tools, and equipment to test performance of air, steam, and hydronic distribution systems; special exhaust; and other distribution systems, including HVAC&R terminal equipment and unitary equipment.
		6. Vibration and Sound Tests: Provide technicians, instrumentation, tools, and equipment to test performance of vibration isolation and seismic controls.
		7. The work included in the commissioning process involves a complete and thorough evaluation of the operation and performance of all HVAC components, systems, and sub-systems.
			1. ALL HVAC systems (incl. controls and building envelope inspection)
			2. Energy Management System (BMS, EMS, DDC)
	12. DEFICIENCIES/NON-CONFORMANCE, COST OF RETESTING, FAILURE DUE TO MANUFACTURER DEFECT

		1. Refer to Division 01 Section “General Commissioning Requirements” for requirements pertaining to deficiencies/non-conformance, cost of retesting, or failure due to manufacturer defect.
	13. APPROVAL

		1. Refer to Division 01 Section “General Commissioning Requirements” for approval procedures.
	14. DEFERRED TESTING

		1. Refer to Division 01 Section “General Commissioning Requirements” for requirements pertaining to deferred testing.
	15. OPERATION AND MAINTENANCE MANUALS

		1. The Operation and Maintenance Manuals shall conform to Contract Documents requirements as stated in Division 01.
		2. Refer to Division 01 Section “General Commissioning Requirements” for the AE and CxA roles in the Operation and Maintenance Manual contribution, review and approval process.
		3. An updated as-built version of the control drawings and sequences of operation shall be included in the final controls O&M manual submittal.
	16. TRAINING OF OWNER PERSONNEL

		1. Refer to Division 01 Section “General Commissioning Requirements” for requirements pertaining to training.
		2. Mechanical Contractor. The mechanical contractor shall have the following training responsibilities:
			1. Provide the CxA with a training plan two weeks before the planned training.
			2. Provide designated Owner personnel with comprehensive orientation and training in the understanding of the systems and the operation and maintenance of each piece of HVAC equipment including, but not limited to, all HVAC equipment (ex. pumps, heat exchangers, chillers, heat rejection equipment, air conditioning units, air handling units, fans, terminal units, controls and water treatment systems, etc.)
			3. Training shall normally start with classroom sessions followed by hands-on training on each piece of equipment, which shall illustrate the various modes of operation, including startup, shutdown, fire/smoke alarm, power failure, etc.
			4. During any demonstration, should the system fail to perform in accordance with the requirements of the O&M manual or sequence of operations, the system will be repaired & adjusted as necessary with the demonstration repeated to CxA’s satisfaction.
			5. The appropriate trade or manufacturer's representative shall provide the instructions on each major piece of equipment. This person may be the start-up technician for the piece of equipment, the installing contractor or manufacturer’s representative. Practical building operating expertise as well as in-depth knowledge of all modes of operation of the specific piece of equipment are required. More than one party may be required to execute the training.
			6. The training sessions shall follow the outline in the Table of Contents of the operation and maintenance manual and illustrate whenever possible the use of the O&M manuals for reference.
			7. Training shall include:
				1. Use of the printed installation, operation and maintenance instruction material included in the O&M manuals.
				2. A review of the written O&M instructions emphasizing safe and proper operating requirements, preventative maintenance, special tools needed and spare parts inventory suggestions. The training shall include start-up, operation in all modes possible, shut-down, seasonal changeover and any emergency procedures.
				3. Discussion of relevant health and safety issues and concerns.
				4. Discussion of warranties and guarantees.
				5. Common troubleshooting problems and solutions.
				6. Explanatory information included in the O&M manuals and the location of all plans and manuals in the facility.
				7. Discussion of any peculiarities of equipment installation or operation.
				8. The format and training agenda in The HVAC Commissioning Process, ASHRAE Guideline 1 (current edition), is recommended.
			8. Hands-on training shall include start-up, operation in all modes possible, including manual, shutdown and any emergency procedures and preventative maintenance for all pieces of equipment.
			9. The mechanical contractor shall fully explain and demonstrate the operation, function and overrides of any local packaged controls, not controlled by the central control system.
			10. Training shall occur after functional testing is complete, unless approved otherwise by the Owner.
		3. Controls Contractor. The controls contractor shall have the following training responsibilities:
			1. Provide the CxA and AOR/MEOR and Owner with a training plan four weeks before the planned training.
			2. The controls contractor shall provide designated Owner personnel training on the control system in this facility. The intent is to instruct the Owner clearly and completely on all the capabilities of the control system.
			3. Training manuals. The standard operating manual for the system and any special training manuals shall be in searchable electronic format. Copy of manuals will be provided for each trainee. In addition, copies of the system technical manual will be demonstrated during training and copies submitted with the O&M manuals. Manuals shall include detailed description of the subject matter for each session. The manuals will cover all control sequences and have a definitions section that fully describes all relevant words used in the manuals and in all software displays. Manuals will be approved by the CxA and AOR/MEOR and Owner. Copies of audio visuals shall be delivered to the Owner.
			4. The trainings will be tailored to the needs and skill-level of the trainees.
			5. The trainers will be knowledgeable on the system and its use in buildings. For the on-site sessions, the most qualified trainer(s) will be used. The Owner shall approve the instructor prior to scheduling the training.
			6. During any demonstration, should the system fail to perform in accordance with the requirements of the O&M manual or sequence of operations, the system will be repaired or adjusted as necessary, and the demonstration repeated.
			7. The controls contractor shall attend sessions other than the controls training, as requested, to discuss the interaction of the controls system as it relates to the equipment being discussed.
		4. TAB. The TAB contractor shall have the following training responsibilities:
			1. TAB shall meet for 4 hours with facility staff after completion of TAB and instruct them on the following:
				1. Go over the final TAB report, explaining the layout and meanings of each data type.
				2. Discuss any outstanding deficient items in control, ducting or design that may affect the proper delivery of air or water.
				3. Identify and discuss any terminal units, duct runs, diffusers, coils, fans and pumps that are close to or are not meeting their design capacity.
				4. Discuss any temporary settings and steps to finalize them for any areas that are not finished.
				5. Other relevant information that may be useful for facility operations, relative to TAB.

**END OF SECTION 23 08 00**

**SECTION 23 09 23 – DIRECT DIGITAL CONTROL (DDC) SYSTEM FOR HVAC**

PART 1 – GENERAL

This document intent is to provide system requirements and certain Caltech preferences for Building Management System (BMS) that is consistent with California Institute of Technology System Architecture. This Section applies to the control of but not limited to all heating, ventilating, and air conditioning (HVAC) Work and the monitoring of electrical power and water usage by category. Coordinate with applicable Sections as required.

* 1. RELATED DOCUMENTS

		1. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.
		2. Where conflicts exist between the specification and/or drawings, the more stringent requirement shall apply.
		3. Section 23 08 00 HVAC Commissioning Requirements
		4. Refer to Sections in Division 22,23,26 and 27 for general requirements pertaining to mechanical, plumbing, electrical and communications work.
		5. Refer to current Caltech standards on-line for latest versions for the project. [https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards) Included appendices are for reference only.
			1. Appendix A – Asset Keywords and schedule tags – Revision 1.1
			2. Appendix B – BMS Naming Standards – Revision 2.0
			3. Appendix C – BMS Programming/Graphics Standards – Revision 2.0
			4. Appendix D – Sequence of Operations – Revision x.x
			5. Appendix E – Standard object name request form
			6. Appendix F – Building controller naming/IP request form
	2. RELATED SCOPE OF WORK

		1. Products furnished and installed under different section.
			1. Duct-mounted airflow stations under Section 23 XX XX contractor.
			2. Fan-mounted airflow stations under Section 23 XX XX contractor.
			3. KW meters under Section 26 XX XX contractor.
		2. Products furnished but not installed under this section.
			1. Furnish control valves, sensor wells, flow meters, and gauge taps to Section 23 XX XX contractor.
			2. Furnish flow meters to Section 23 XX XX contractor.
		3. Products installed but not furnished under this section.
			1. Provide control wiring in conduit to the variable frequency drive controllers furnished under Section 23 XX XX and motor starters furnished under Section 26 XX XX.
			2. Coordinate damper, valve actuator requirements for any control dampers, valves furnished and installed by others, to ensure compatibility with BMS controllers. Provide damper actuators for all control dampers in cases where dampers are furnished and installed by others without actuators.
		4. BMS Integration
			1. Integrate to the systems listed in this section, indicated in BMS Integration Table and/or indicated on the Drawings.
			2. Provide wiring and conduit under this section between BMS hardware and integration equipment.
			3. Provide labor and BMS hardware to successfully integrate.
	3. DEFINITIONS

		1. Abbreviations
			1. AC Air Conditioning Unit
			2. AHU Air Handling Unit
			3. AI Analog Input
			4. AO Analog Output
			5. AOR Architect of Record
			6. BMS Building Management System
			7. BTU British Thermal Unit
			8. CAV Constant Air Volume, Terminal Unit
			9. CC Cooling Coil
			10. CFM Cubic Feet per Minute
			11. CH Chiller of Chilled
			12. CHW Chilled Water
			13. CHWP Chilled Water Pump
			14. CHWR Chilled Water Return
			15. CHWS Chilled Water Supply
			16. CO Carbon Monoxide
			17. CO2 Carbon Dioxide
			18. COV Change of Values
			19. CT Cooling Tower
			20. CTP Cooling Tower Pump
			21. CU Condensing Unit
			22. CW Condensing Unit
			23. CWP Condenser Water Pump
			24. CWR Condenser Water Return
			25. CWS Condenser Water Supply
			26. Cx Commissioning
			27. CxA Commissioning Authority
			28. DB Dry Bulb Temperature
			29. DDC Direct-digital controls
			30. DEG F Degrees Fahrenheit
			31. DI Digital Input
			32. DO Digital Output
			33. DP Differential Pressure
			34. DT Dewpoint Temperature
			35. (E) Existing
			36. EA Exhaust Air
			37. EAT Entering Air Temperature
			38. FCU Fan Coil Unit
			39. FDD Fault Detection Diagnostics
			40. FEF Fume Hood Exhaust Fan
			41. FF Final Filter
			42. FH Fume Hood
			43. FLA Full Load Amp
			44. FLA Full Load Amp
			45. FPM Feet per Minute
			46. FPT Functional Performance Test
			47. FS Flow Switch
			48. FSD Fire/Smoke Damper, Combination
			49. GA Gauge
			50. GEF Garage Exhaust Fan
			51. GPH Gallon per Hour
			52. GPM Gallon per Minute
			53. HC Heating Coil
			54. HHW Heating Hot Water
			55. HHWP Heating Hot Water Pump
			56. HHWR Heating Hot Water Return
			57. HHWS Heating Hot Water Supply
			58. HP Heat Pump or Horsepower
			59. HX Heat Exchanger
			60. HZ Hertz
			61. LAN Local area network
			62. LAT Leaving Air Temperature
			63. LEF Laboratory Exhaust Fan
			64. MAX Maximum
			65. MEOR Mechanical Engineer of Record
			66. MIN Minimum
			67. MS/TP Master-slave/token-passing
			68. MUA Make-up Air
			69. (N) New
			70. NC Normally Closed
			71. NO Normally Open
			72. OA Outside Air
			73. PF Pre-Filter
			74. POC Point of Connection
			75. PPM Parts Per Million
			76. PRV Pressure Reducing Valve
			77. PSID Differential Pressure
			78. PSIG Pounds Per Square Inch, Gauge Pressure
			79. (R) Relocated
			80. RA Return Air
			81. RF Return Fan
			82. RH Relative Humidity
			83. RTU Rooftop Unit
			84. S Sensor
			85. SA Supply Air
			86. SD Smoke Detector, Damper
			87. SF Supply Fan
			88. SP Static Pressure
			89. SW Switch
			90. T Temperature, Thermostat
			91. UH Unit Heater
			92. VAV Variable Air Volume, Terminal Unit
			93. VFD Variable Frequency Drive
			94. WB Wet Bulb Temperature
			95. WC Water Column
			96. WSHP Water Source Heat Pump
		2. Algorithm: A logical procedure for solving a recurrent mathematical problem. A prescribed set of well-defined rules or processes for solving a problem in a finite number of steps.
		3. Analog: A continuously varying signal value, such as current, flow, pressure, or temperature.
		4. BACnet Specific Definitions:
			1. BACnet: Building Automation Control Network Protocol, ASHRAE 135. A communications protocol allowing devices to communicate data over and services over a network.
			2. BACnet Interoperability Building Blocks (BIBBs): BIBB defines a small portion of BACnet functionality that is needed to perform a particular task. BIBBs are combined to build the BACnet functional requirements for a device.
			3. BACnet/IP: Defines and allows using a reserved UDP socket to transmit BACnet messages over IP networks. A BACnet/IP network is a collection of one or more IP subnetworks that share the same BACnet network number.
			4. BACnet Testing Laboratories (BTL): Organization responsible for testing products for compliance with ASHRAE 135, operated under direction of BACnet International.
			5. PICS (Protocol Implementation Conformance Statement): Written document that identifies the particular options specified by BACnet that are implemented in a device.
		5. Binary: Two-state signal where a high signal level represents ON" or "OPEN" condition and a low signal level represents "OFF" or "CLOSED" condition. "Digital" is sometimes used interchangeably with "Binary" to indicate a two-state signal.
		6. "Concealed": Embedded in masonry or other construction, installed in furred spaces, within couple partitions or hung ceilings, in trenches, in crawl spaces, or in enclosures.
		7. Controller: Generic term for any standalone, microprocessor-based, digital controller residing on a network, used for local or global control. Three types of controllers are indicated: Network Controller, Programmable Application Controller, and Application-Specific Controller.
		8. DDC System Provider: Authorized representative of, and trained by, DDC system manufacturer and responsible for execution of DDC system Work indicated.
		9. Distributed Control: Processing of system data is decentralized, and control decisions are made at subsystem level. System operational programs and information are provided to remote subsystems and status is reported back. On loss of communication, subsystems shall be capable of operating in a standalone mode using the last best available data.
		10. "Exposed": Not installed underground or "concealed" as defined above
		11. "Furnish" : To supply and deliver to the project site, ready for unloading, unpacking, assembly, installation.
		12. Fox Protocol: Native Niagara peer to peer protocol language.
		13. Gateway: Bidirectional protocol translator that connects control systems that use different communication protocols.
		14. Haystack: Open protocol for semantic tagging library and communication drivers
		15. "Install": To erect, mount, and connect complete with related accessories.
		16. I/O: System through which information is received and transmitted. I/O refers to analog input (AI), binary input (BI), analog output (AO) and binary output (BO). Analog signals are continuous and represent control influences such as flow, level, moisture, pressure, and temperature. Binary signals convert electronic signals to digital pulses (values) and generally represent two-position operating and alarm status. "Digital," (DI and (DO), is sometimes used interchangeably with "Binary," (BI) and (BO), respectively.
		17. LNS: LonWorks Network Services.
		18. LON: LonWorks free topology
		19. Low Voltage: As defined in NFPA 70 for circuits and equipment operating at less than 50 V or for remote-control, signaling power-limited circuits.
		20. MS/TP: Master-slave/token-passing, IEE 8802-3. Datalink protocol LAN option that uses twisted-pair wire for low-speed communication.
		21. Network Controller: Digital controller, which supports a family of programmable application controllers and application-specific controllers, that communicates on peer-to-peer network for transmission of global data.
		22. Network Repeater: Device that receives data packet from one network and rebroadcasts it to another network. No routing information is added to protocol.
		23. Peer to Peer: Networking architecture that treats all network stations as equal partners.
		24. "Piping": Pipe, tube, fittings, valves, controls, strainers, hangers, supports, union, traps, drains, insulation, and related items.
		25. "Provide": To supply, install and connect up complete and ready for safe and regular operation of particular work referred to unless specifically otherwise noted.
		26. Router: Device connecting two or more networks at network layer.
		27. "Supply": To purchase, procure, acquire, and deliver complete with related accessories.
		28. TCP/IP: Transport control protocol/Internet protocol.
		29. UPS: Uninterruptible power supply.
		30. USB: Universal Serial Bus.
		31. User Datagram Protocol (UDP): This protocol assumes that the IP is used as the underlying protocol.
		32. "Wiring": Raceway, fittings, wire, boxes, and related items.
		33. "Work": Labor, materials, equipment, apparatus, controls, accessories, and other items required for proper and complete installation
	4. REFERENCE STANDARDS

		1. Work under this Section is subject to requirements of Contract Documents including General Conditions, Supplementary Conditions, and sections under Division 01 General Requirements.
		2. The latest edition of the following standards and codes in effect and amended as of supplier's proposal date, and any applicable subsections thereof, shall govern design and selection of equipment and material supplied:
			1. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).
			2. ANSI/ASHRAE Standard 135, BACnet.
			3. ASHRAE Guideline 36-2018, High-Performance Sequences of Operation for HVAC Systems.
			4. California Building Code (CBC).
			5. California Mechanical Code (CMC)
			6. California Plumbing Code (CPC)
			7. International Building Code (IBC), including local State and Local amendments.
			8. UL 508 & UL 508A Underwriters Laboratories Standard for Energy Management Equipment. Canada and the US.
			9. UL 916 Underwriters Laboratories Standard for Energy Management Equipment. Canada and the US.
			10. National Electrical Code (NEC).
			11. FCC Part 15, Subpart J, Class A.
			12. EMC Directive 89/336/EEC (European CE Mark).
		3. State, and federal regulations and codes in effect as of contract date.
	5. STANDARDS COMPLIANCE

		1. All equipment and material to be from manufacturer's regular production, UL and/or ULC or CSA certified, manufactured to standard quoted plus additional specified requirements.
		2. Where UL and/or ULC or CSA certified equipment is not available submit such equipment to inspection authorities for special inspection and approval before delivery to site.
		3. For materials whose compliance with organizational standards/codes/specifications is not regulated by an organization using its own listing or label as proof of compliance, furnish certificate stating that material complies with applicable referenced standard or specification.
	6. ACCEPTABLE CONTROL CONTRACTORS

		1. The BMS System shall be designed, installed, commissioned, and serviced by Caltech pre-qualified Control Contractor.
			1. Control Contractor shall have full-service office within 100 miles of project site. Full-service office is defined as being home office of applications engineers, supervisors, and field technicians, having complete parts inventory, and having required test and diagnostic equipment.
			2. Control Contractors shall be a licensed Tridium "EC-Net" Dealer and shall have a minimum of (2) factory certified technicians permanently employed on staff in local office performing project prior to the bid.
			3. The control contractor (Distech Approved Controls Contractor) shall be an authorized Distech supplier for the field level controllers. The programmable and application specific controllers shall be the Distech Controls product. Distech controls from 3rd party distribution channels or other manufacturer controller brands that operate with BACnet or LON protocol will not be accepted.
			4. The control contractor's officers, and senior staff must each have at least (5) years of experience with Tridium projects of equal size and complexity. The controls supplier shall be an independent contractor and shall not be affiliated with any manufacturer branch Control System.
			5. Contractor shall be selected from Caltech pre-approved controls contractors.
		2. Control Contractor’s Labor shall include, but not be limited to:
			1. Engineering services to size unscheduled valves and dampers based on design criteria and confirm sizing of scheduled valves and dampers.
			2. Engineering services to produce requested submittals and working construction drawings and record drawings as specified here within.
			3. Engineering services for required software programming.
			4. Engineering services for graphics programming specified.
			5. Engineering services for bench testing sequences and graphics in conjunction with Caltech BMS Controls Shop representatives.
			6. Project management services as single point of contact to coordinate construction related control activities.
			7. Field technicians for installation of control wiring and related control devices.
			8. Field technicians to startup, calibrate, adjust, and tune control loops.
			9. Field technicians to perform system checkout and testing, and to complete required reports.
			10. Field technicians to assist Mechanical Contractor and Testing and Balancing (TAB) Contractor in adjusting controls and determining setpoints related to TAB work.
			11. Field representatives and/or classroom instructors to provide Owner training as specified.
			12. Control Contractor shall be responsible for complete installation of control devices (except as noted), including wiring terminations at controller and sensor locations to accomplish control sequences specified in project manual and/or on drawings.
			13. Control Contractor shall be responsible for additional instrumentation described in point schedules found in Contract Documents, which may not be directly related to specified control sequences.
			14. Control contractor shall utilize Caltech standard tagging convention for all devices and sensors.
		3. Contractors substituting non-approved Campus Control Contractor in their bid package will be considered non-compliant with the bid documents and consequently their bid(s) will be rejected.
		4. Commissioning Scope: In addition to the commissioning scope indicated herein and in the individual System Sections, the Controls Contractor shall work and cooperate fully with Caltech Third-Party Commissioning Agent in demonstrating that the BMS is in compliance with the approved design.
	7. SYSTEM DESCRIPTION

		1. This Section includes Building Management System (BMS) control equipment for HVAC primary systems and zone terminal heating and cooling units not supplied with factory wired controls.
		2. Caltech BMS is a multi-tiered system comprised of:
			1. Tier 1 (BMS VLAN) with servers running Tridium Niagara 4 software and Tridium Niagara 4 Network Controllers (JACEs).
			2. Tier 2 Field Based Controls which connect to the open framework Tridium Niagara 4 Network Controllers.
				1. The following protocols BACnet, LonWorks, and Modbus are approved for use on Tier 2 and shall not connect directly to Tier 1.
			3. BACnet is approved for HVAC controls on new work.
			4. Modbus is required for Energy Metering and Monitoring (Electrical, Thermal, Water and varied Gas or Liquid Flows).
			5. Addition and/or expansion to existing buildings with LonWorks systems with LonTalk LONMARK controls shall be submitted within 14 calendar days after award of contract to Caltech BMS Controls Shop for review and approval or where Caltech explicitly requires that the LonTalk architecture must remain in place.
			6. Approved Lon systems shall use LonTalk as its native protocol. System components shall be certified by LONMARK and display the LONMARK® logo where applicable.
			7. Approved Lon systems shall support seamless integration with Niagara 4 Network controller.
		3. The BMS BACnet controls shall provide an open automation infrastructure that will integrate the new and existing systems into a unified platform. The system shall be a distributed programmable controller network as defined by ANSI/ASHRAE Standard 135-2001 BACnet for Building Automation and Control Systems.
		4. Other Tridium products that have been private labeled and distributed through other controls manufacturers will not be accepted without written approval by Caltech BMS Controls Shop.
		5. Tier 2 field-based controllers “System, terminal and unitary controller” level equipment controllers (air handlers, fan coils, terminal units, chilled and hot water stations, etc.) shall be native BACnet controllers with no proprietary extensions or requirements for 3rd party software for on-going maintenance.
			1. Controls Contractor is responsible for delivering all controls, site licensing, programming and a BACnet based control network that will allow the controllers to be integrated to the related Building Niagara 4 JACEs, as well as maintain basic control-level in the event of a loss of communication between the Niagara system and the Control-level controls.
			2. The system shall be a distributed programmable controller network as defined by ANSI/ASHRAE Standard 135-2015 plus Addenda BACnet for Building Automation and Control Systems. Provide all hardware and software necessary to add, modify and delete system objects; add or change application programs; create or modify time schedules; and setup trend logs.
			3. All HVAC Control-level level monitoring devices and controllers, including terminal units, shall be connected via BACnet. BACnet network for Control-level shall be a secondary managed switch network isolated from Campus Level WAN network. Secondary BACnet network addressing to be coordinated with all other BACnet systems through the Control-level, including but not limited to lighting controls, metering, air flow monitoring, and other specialty systems.
			4. Approved Control-level BACnet Equipment and Zone Controllers.
				1. Distech,
				2. Caltech BMS Controls Shop approved equal
			5. The BMS controllers shall be programmable, which allows owner facilities staff to adjust control sequences, set points and operation schedules from remote or local locations.
			6. All electrical utility meters shall communicate to campus Niagara servers through Modbus protocol. (To be defined project by project as identified on the sequence and network diagram.)
			7. Coordinate BACnet addressability to enable integration with lighting control systems. (To be defined project by project as identified on the sequence and network diagram.)
			8. The installation of the control system shall be performed in accordance with approved shop drawings, bill of materials, point-to-point wiring diagrams and sequences of operation.
			9. Coordinate means and methods for the delivery of turnkey BMS controllers with each discipline. Wherever possible installation of terminal unit controllers on mechanical equipment prior to on site installation is preferred.
			10. All materials and equipment shall be standard components, regularly manufactured for building automation systems and not custom designed specifically for this project. All systems components shall have been thoroughly tested and proven in actual use for at least two years in the U.S. commercial or industrial controls industry.
			11. No mechanical equipment used for fire life safety or smoke control shall be programmed for this service by the BMS.
			12. The space zone control method is dry bulb temperature with additional instrumentation as specifically shown on the drawings for specialty applications. Consideration shall be given to alternate technologies, i.e., infrared temperature sensing, combination temperature/humidity/CO2 on a case-by- case basis.
	8. SCOPE OF WORK

		1. Furnish and install a fully integrated Building Management System, incorporating direct digital control (DDC) for environmental controls, energy management, equipment monitoring and control, and subsystems as specified. The installation of the control system shall be performed under the direct supervision of the controls contractor with approved shop drawings, bill of materials, point-to-point wiring diagrams, graphic displays, and sequences of operation.
		2. All materials and equipment shall be standard components, regularly manufactured for Building Management systems and not custom designed specifically for this project. All systems components shall have been thoroughly tested and proven in actual use for at least two years in the U.S. commercial or industrial controls industry.
		3. Provide all BMS communication and instrumentation wiring for a complete and operable system. All wiring shall be installed in accordance with local standards and codes and the specifications of this project.
		4. Provide integration of new products and data into the existing campus Niagara Supervisor following the guideline listed in the specifications of this project. Coordination with Caltech BMS Controls Shop as required to gaining access to the campus supervisor server.
		5. Comply with the Caltech’s Campus Standards for graphic development, graphic navigation, point naming convention, controller programming and analog point change of value limits. Reference Appendices included in the specifications are for reference only. For the latest Caltech standards check on-line for latest versions for the project. [https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards)
		6. Provide support for issue resolution of identified 3rd party commissioning measures.
	9. WORK BY OTHERS

		1. Section 23 Mechanical Contractor shall install all wells, valves, pressure taps, control dampers, air flow stations, flow meters, etc. that may be furnished by BMS controls subcontractor. Mechanical Contractor is also responsible for BMS control panel and instrumentation factory mounting charges on primary HVAC equipment and terminal units before shipping to the job site.
		2. Section 26 Electrical Contractor shall provide:
			1. 120V power junction boxes for all BMS and/or temperature control panels.
			2. Wiring of all power feeds through all disconnects and starters to electrical motors.
			3. Installation and wiring of Variable Frequency Drives.
			4. Wiring of any remote start/stop switches and manual or automatic motor speed control devices.
			5. All fire alarm interface wiring to HVAC equipment, fire/smoke dampers or other devices required for fire safety shutdown or smoke control.
		3. BMS Campus Ethernet network, including all hardware (routers, switches, firewalls, patch panels, patch cords, cabinets, etc.) is responsibility of Caltech.
			1. Controls Contractor shall be responsible for designing the communication networks and coordination with Caltech IT department.
			2. Secondary IP based controller network designed, furnished, and installed by Controls Contractor. Design shall be submitted for review and approval by Caltech BMS Controls Shop representative prior to start of work.
	10. QUALITY ASSURANCE

		1. The BMS system shall be engineered, installed, commissioned, and serviced by the manufacturers authorized local representative. All personnel shall be factory trained with a minimum of 3 years’ experience in the installation and maintenance of BMS and HVAC systems similar in size and complexity to the Caltech BMS system. The manufacturer shall also have a maintenance service center operating 24/7 within 50 miles of the Caltech campus. The service center shall have technical staff, spare parts inventory and necessary test and diagnostic equipment.
		2. The Contractor shall have at least 2 full-time journeyman employees who are Tridium Niagara 4 Certified with relevant project experience on at least 3 projects of similar size and complexity at the time of bid and contract award. One of these employees must be included in a project staffing plan and assigned to the project upon award for its duration. Contractor to provide resumes for all staff members included in the project staffing plan. Resume to include years in trade and relevant project examples for each member of staff.
		3. All BACnet controllers shall be BTL certified.
		4. Materials and equipment shall be the catalogued products of manufacturers regularly engaged in production and installation of automatic environmental control systems and shall be the manufacturer’s latest standard design that complies with these specification requirements.
		5. All systems, equipment, components, accessories, software, and installation hardware must be new, free from defects and currently in production.
		6. Furnished instruments, control devices of same product type, service and/or application shall be of same manufacturer throughout the project.
		7. Install and operationally check systems utilizing factory-trained competent technicians skilled in the setting and adjustment of equipment used in this project.
		8. Test, adjust, and calibrate all end-to-end instruments installed by the contractor prior to commissioning.
		9. Follow project communication protocol for all correspondence. Any changes, decisions, etc. must be properly documented and approved by the relevant Caltech Representative.
		10. Request for Interpretation (RFI) shall include:
			1. Referenced drawing and/or Specification Section number
			2. Single request per RFI
			3. Single proposed solution per RFI
			4. Attached sketch of solution (if applicable)
			5. Attached specification verbiage (if applicable)
			6. Contact person
			7. Incomplete RFI’s will be returned without response
			8. RFI answers are for clarification only and do not authorize additional work or change orders.
		11. Install devices in appropriate enclosure and in an accessible location.
		12. Install systems and devices in a neat, workmanlike manner and in accordance with manufacturer's recommendations.
		13. Continually monitor the field installation for code compliance and quality workmanship.
		14. Remove and re-install any systems or devices where installation is deemed of poor quality by Caltech or MEOR.
		15. Comply with all health and safety regulations.
		16. Include automatic restart logic for all controllers due to loss of power, safeties, fire alarm shutdown, etc.
		17. All electronic equipment shall conform to the requirements of FCC Regulation, Part 15, Section 15, governing Radio Frequency Electromagnetic Interference.
		18. Cables to end devices shall be uninterrupted. Splices in any of the wiring associated with the system installation not acceptable.
		19. Controls Contractor is required to participate in any required inspections and validations by general contractor, project inspectors, owners, agents, consultants or any other party requiring inspection and validation.
		20. It is the responsibility of the Controls Contractor to provide any necessary on-site facilities or equipment to execute their work including trenching, scaffolding, lifts, hoists, storage, site offices, communication equipment, etc.
		21. All wire and cable labels must be installed within 8” (eight inches) of its termination point.
		22. Critical BMS control devices and panels are typically shown in approximate locations on mechanical drawings and are subject to final field validation. Actual field installation of panels, thermostats, sensors, etc. must be validated through the appropriate job site channels prior to installation. Otherwise, the possible relocation of panels or devices shall be at the Controls Contractor's expense.
		23. It is the responsibility of the Controls Contractor to turn over a trouble-free communication bus free of all ground faults, open lines, and shorts prior to power up.
		24. All communications wiring routing shall be documented on the mechanical or electrical plans. Device addressing and the location of bus end-of-lines, repeaters, routers, coordinators, power supplies and similar equipment shall be documented on the mechanical or electrical plans. These plans shall be kept current and made available, on as progress basis, upon request by the GC or mechanical contractor and it shall be turned over as part of the as-built documentation.
		25. Provide and install all fire stopping and sealing of the electrical/mechanical penetrations applicable to BMS work. This includes all areas associated with electrical/mechanical penetrations including the area around and inside sleeves and raceways that may provide a path for air infiltration. All fire stopping and sealing must be installed to meet the applicable project specifications and/or other requirements.
	11. SYSTEM PERFORMANCE

		1. Provide instrumentation to meet or exceed variables indicated. Instrumentation for control of operating rooms, patient care, libraries, museums, vivariums, and other specialty applications shall be as noted on the drawings or sequences of operation.
		2. Control sensor performance requirements: Control variables indicated within the following limits:
			1. Flow:
				1. Air, Ducts and Equipment, except Terminal Units: Plus, or minus 5 percent of full scale.
				2. Water: Within 2 percent of design flow rate.
			2. Gas:
				1. Carbon Dioxide: Plus, or minus 50 ppm with a 10-year calibration – Free Feature.
				2. Carbon Monoxide: Plus, or minus 5 percent of reading.
			3. Moisture (Relative Humidity):
				1. Air: Plus, or minus 2 to 3 percent.
				2. Space: Plus, or minus 2 to 3 percent.
				3. Outdoor: Plus, or minus 2 to 3 percent.
			4. Pressure:
				1. Air, Ducts and Equipment: Plus, or minus 0.1-inch w.c..
				2. Space: Plus, or minus 0.01-inch w.c.
				3. Water: Plus, or minus 2 percent of full scale.
			5. Temperature, Dry Bulb:
				1. Air: Plus, or minus 1 deg F.
				2. Space comfort: Plus, or minus 2 deg F of full scale, unless indicated otherwise in project specific design requirements.
				3. Lab Equipment Temperature: Plus, or minus 0.5 def F of full scale, unless indicated otherwise in project specific design requirements.
				4. Water: Plus, or minus 1 deg F.
		3. Environmental Conditions for Controllers, Gateways, and Routers:
			1. Products shall operate without performance degradation under ambient environmental temperature, pressure and humidity conditions encountered for installed location.
			2. Products shall be protected with enclosures satisfying the following minimum requirements unless more stringent requirements are indicated. Products not available with integral enclosures complying with requirements indicated shall be housed in protective secondary enclosures. Installed location shall dictate the following NEMA 250 enclosure requirements:
				1. Outdoors, Protected: Type 3.
				2. Outdoors, Unprotected: Type 4X.
				3. Indoors, Heated with Filtered Ventilation: Type 1.
				4. Indoors, Heated with Non-Filtered Ventilation: Type 12.
				5. Indoors, Heated and Air Conditioned: Type 1.
				6. Mechanical Equipment Rooms:

Chiller and Boiler Rooms: Type 4.

Air-Moving Equipment Rooms: Type 2.

* + - * 1. Localized Areas Exposed to Washdown: Type 4X.
				2. Within Duct Systems and Air-Moving Equipment Not Exposed to Possible Condensation: Type 3.
				3. Within Duct Systems and Air-Moving Equipment Exposed to Possible Condensation: Type 4.
		1. Environmental Conditions for Instruments and Actuators:
			1. Instruments and actuators shall operate without performance degradation under the ambient environmental temperature, pressure, humidity, and vibration conditions specified and encountered for installed location.
			2. Instruments, actuators, and accessories shall be protected with enclosures satisfying the following minimum requirements unless more stringent requirements are indicated. Instruments and actuators not available with integral enclosures complying with requirements indicated shall be housed in protective secondary enclosures. Installed location shall dictate the following NEMA 250 enclosure requirements:
				1. Outdoors, Protected: Type 3.
				2. Outdoors, Unprotected: Type 4X.
				3. Indoors, Heated with Filtered Ventilation: Type 1.
				4. Indoors, Heated with Non-Filtered Ventilation: Type 2.
				5. Indoors, Heated and Air-conditioned: Type 1.
				6. Mechanical Equipment Rooms:

Chiller and Boiler Rooms: Type 4.

Air-Moving Equipment Rooms: Type 2.

* + - * 1. Localized Areas Exposed to Wash down: Type 4X.
				2. Within Duct Systems and Air-Moving Equipment Not Exposed to Possible Condensation: Type 3.
				3. Within Duct Systems and Air-Moving Equipment Exposed to Possible Condensation: Type 4.
	1. SUBMITTALS
		1. Specification Compliance: Provide an electronic copy list of products identifying:
			1. Comply - vendor complies or exceeds this requirement
			2. Deviation - vendor deviated from specification requirement but provides similar operational and functional capability. Vendor to describe the deviation and how its product meets the specification performance requirement. Indicate specification paragraph.
			3. Non-Compliant - vendor's proposed product does not meet the specification requirement. Indicate specification paragraph.
		2. Reference Appendices included in the specifications for the latest Caltech Campus Standards and requirements.
		3. All submittals, record documents, operations manuals should be indexed. PDF documents shall include searchable text. Scanned documents are not acceptable. Provide the following submittals with a minimum drawing size of 11 x 17.
			1. Network Architecture Diagram. Network architecture includes but is not limited to:
				1. Nodes. Each TCP/IP node shall include:

Device Description

Device Name

Primary Campus IP Address (Coordination with Caltech BMS Controls Shop is required. For security purposes do not list on drawings)

Secondary IP Address (include on drawings, coordination with Caltech BMS Controls Shop is required.)

BACnet Instances (Coordination with Caltech BMS Controls Shop is required)

Physical location. (Room number or location description)

* + - * 1. Switches and routers
				2. Integrated systems and/or sub-systems
				3. Dedicated I/O locations
		1. System Control Drawings
			1. Shall follow Caltech template guidelines
			2. Instrumentation with point name, range, and address
			3. Sequence of Operation
			4. Bill of Material
			5. Schematic flow diagrams showing fans, pumps, coils, dampers, valves, sensing devices, safety devices, and control devices.
			6. Wiring Diagrams: Power, signal, and control wiring. Differentiate between manufacturer-installed and field-installed wiring.
			7. Details of control panel faces, including controls, instruments, and labeling.
			8. Schedule of dampers provided by BMS contractor including size, leakage, and flow characteristics.
			9. Schedule of valves including size, type, leakage, and flow characteristics.
		2. Detailed panel layout & wiring drawings
			1. Wiring diagram copies shall be laminated and attached to the control panel door
		3. Points List I/O Spreadsheet
			1. Point Name
			2. Type
			3. Description
			4. Function
			5. Address
			6. Signal (input or output)
			7. Device Range
			8. Engineering Units
			9. Control point or set point (Yes / No)
			10. Monitoring point (Yes / No)
			11. Intermediate point (Yes / No)
			12. Calculated point (Yes / No)
		4. Controller Spreadsheet
			1. Model Number
			2. Firmware revision
			3. All IP Configuration Parameters
			4. MAC address
			5. License Information
		5. Sequences of Operations
			1. Include sequences based on the SOO provided by the engineer of record.
			2. Sequences shall be modified as necessary to meet the application requirements.
			3. Sequences for large special function rooms such as auditorium, classroom, banquet halls, training centers with multiple mechanical zone equipment, shall meet requirements provided by MEOR. Contractor to submit specific details regarding sensor selection, quantity, location to properly support a control strategy that meets the requirements of the space. If not specified by MEOR, coordination with the Caltech BMS Controls Shop is required prior to installation or programming of BMS components in these space types.
			4. Provide custom demand control ventilation sequences at the zone level to meet title 24 ventilation requirements.
		6. Alarms: Each alarm in the submission shall be provided per Caltech standards.
			1. Alarm name and description and type
			2. Alarm type (AI, BI, AV, BV)
			3. Alarm event type (Change of State, Floating Limit, etc.)
			4. Alarm differentials (automatically adjust with setpoints)
			5. Units
			6. Limits or state
			7. Priority
			8. Message
		7. Product Data: For each product submission shall include the following:
			1. Table of contents for each submission.
			2. Product data sheets for all required components and accessories.
			3. For data sheets that apply to multiple product configurations, identify actual model number and option selections to be installed.
			4. Provide BACnet points list for all controllers detailing the description, function, address, and specific naming of each point so that it may be easily identified upon discovery during integration to the building supervisor database.
		8. System Integration Plan: For new and existing systems, provide a comprehensive plan for integration to the system that reflects both the components and architecture. The finished plan should act as a new record document for the entire automation system.
			1. Network architecture to include nodes, switches, routers, and integrated sub-systems.
			2. Points lists with an integration matrix detailing systems and protocols to be used.
			3. Workflow processes to integrate systems.
			4. Communication hardware, software, and protocols to implement full systems integration.
	1. RECORD DRAWINGS

		1. Refer to Division 01 - General Requirements.
		2. Submit revised shop drawings indicating changes made during Project.
		3. Record drawing submittals shall be inclusive of BMS as installed and commissioned.
		4. Update control diagrams to include tuning parameters and set points applicable to systems depicted as of date of system completion. This information shall be incorporated with sequence of operation for each system.
		5. Include floor plans showing location of control panels and routing of BMS network and cabling.
		6. Provide passwords, if used, for back-up and restore functions for each controller.
			1. All administrator passwords for the system, including operation, system management, database management, and device programming must be identified and submitted to the Caltech BMS Controls Shop per security sensitive information transfer protocol.
	2. WARRANTY
		1. Provide all services, installation, materials, and equipment necessary for the successful operation of the project BMS system for a period of one (1) year upon issuance of the project’s Certificate of Substantial Completion. This warranty is in addition to the warranty and defective work requirements of the contract documents.
		2. Sequence of Operation programming issues due to misinterpretations, sequence program errors or deviations from systems original or formally changed operation shall be corrected at no additional cost to the Caltech.
		3. Hidden or assumed conditions that initially appear right but later found to be defective or incorrect shall be rectified to their proper state or purpose. This includes control points data that are improperly placed on the graphics.
		4. Coordinate with Caltech BMS Controls Shop to continuously correct all deficiencies discovered by Caltech during normal occupied building operation. This shall not be counted as training time.
		5. Prior to the beginning of the warranty period, provide a vendor warranty certificate that includes:
			1. Provide warranty issue management practices overview including issue tracking policies.
			2. Warranty begins and end dates
			3. 24-hour dispatch phone number
			4. Service request Email address.
			5. Service personnel with cell phone numbers
			6. Authorized service manager for scheduled repair commitments
		6. Provide updates to operator workstation or web server software, project specific software, graphic software, database software, and firmware that resolve Contractor-identified software deficiencies at no charge during warranty period. If available, Owner can purchase in-warranty service agreement to receive upgrades for functional enhancements associated with above- mentioned items. Do not install updates or upgrades without Owner's written authorization.
		7. Caltech request for a contractor warranty service response shall be on a 24/7 basis. Provide a service request acceptance acknowledgement within one hour.
		8. Non-Emergency Service shall be provided within the next business day after receiving an acceptance notification. Furnish Caltech with telephone numbers and email address where service representatives can be reached during normal business hours. Service personnel shall be at the campus the next business day after receiving a request for service.
		9. Emergency Service shall be provided within two hours after receiving an acceptance notification. Furnish Caltech with telephone numbers and Email address where service representatives can be reached.
		10. Caltech will maintain a log of all warranty issues. A Caltech approved log will be the master project record used to resolve all warranty issues and recommendations.

PART 2 – PRODUCTS

* 1. CONTROLLER MANUFACTURERS

		1. Campus Supervisor shall be Tridium Vykon, running the latest Caltech approved Niagara (4.x) version.
		2. Building Network Controllers shall be Tridium Vykon, running the latest Caltech approved Niagara (4.x) version.
		3. Control-level BACnet Equipment Controllers shall be Distech or approved equal:
		4. All BACnet devices installed shall be BTL listed BACnet devices and shall communicate on Tier 2.
			1. The manufacturer of the hardware and software components as well as its subsidiaries must be a member in good standing of the BACnet International and all controllers used shall be BACnet Listed with documentation on the BACnet website ( <https://www.bacnetinternational.net/btl/search.php>)
		5. Control-level LonWorks Equipment Controllers shall be Lonmark Distech ECL Series or approved equal.
			1. LonTalk shall only be acceptable for sites with existing LonTalk controls architecture where the owner has explicitly stated that the LonTalk architecture must remain in place.
		6. Modbus shall only be acceptable for third party devices.
		7. Proprietary communications protocols shall NOT be acceptable.
		8. A software programming tool shall be provided for this project and adhere to the following guidelines:
			1. All software tools needed for full functional use, including programming of controllers, Niagara 4 Framework network management and expansion, and graphical user interface use and development, of the BAS described within these specifications shall be provided to the owner or his designated agent.
			2. The software programming tool shall be free of charge and openly available for download from the internet.
			3. For any manufacturer that does not have a free programming tool the manufacturer must provide the tool with this project for a minimum of 5 years with proof of availability via letter from the manufacturer.
			4. Any licensing required by the manufacturer now and to the completion of the warranty period, including changes to the licensee of the software tools and the addition of hardware corresponding to the licenses, to allow for a complete and operational system for both normal day to day operation and servicing shall be provided.
	2. INSTRUMENTATION

		1. Instrumentation specified herein is approved campus standards and represents the minimum performance requirements for this project. Product substitutions must be of equal performance and quality and submitted by contractor to MEOR for approval and review by Caltech BMS Controls Shop. This specification section shall take precedence over instrumentation specified or referenced in other sections of this project or as shown on the drawings.
	3. BUILDING MANAGEMENT SYSTEM (BMS) CAMPUS SUPERVISOR
		1. The Campus Supervisor is provided by Caltech BMS Controls Shop and accessed by Controls contractor on as needed basis to execute project specific work.
		2. Controls Contractor shall provide labor only to deliver:
			1. Graphics and alarm management pertaining to project scope.
			2. Integration of Niagara network data from a Niagara Building Supervisors for use developing centralized graphics and importing trends and alarms for use by Caltech BMS Controls Shop personnel.
			3. Caltech BMS Controls Shop typically provides in house graphics and will specify project specific requirements.
		3. Specific user accounts will be created for each Controls contractor requiring access.
		4. Restarting of the Campus Supervisor must be coordinated with the Caltech BMS Controls Shop and approved prior to execution.
		5. All system components shall seamlessly interface with all approved BMS control systems and the building communication protocol. Niagara FOXS is the only protocol integrated to the Campus Supervisor. Other protocols such as BACnet must be first coordinated with Caltech BMS Controls Shop.
		6. All functionality of the Campus Supervisor operating system shall be provided at new and existing workstations including, but not limited to; trending, archiving, custom reports, programming, and scheduling.
		7. Licensing extensions to the Campus Supervisor are the responsibility of the Caltech BMS Controls Shop.
		8. Route data from the Building Supervisor to the Zone Controllers for such functions as:
			1. Point overrides
			2. Schedule commands
			3. Time synchronization
	4. BMS BUILDING SUPERVISOR

		1. The Building Network Controller (Jace) is provided by Controls Contractor. The Building Supervisor controllers shall perform the supervisory control, data logging, alarming, scheduling, and network management functions for the building. Data will be stored on a temporary basis in the Building Supervisor controller. At specified intervals, trend and alarm data will be archived to the Campus Supervisor Server.
			1. Building Network Controller (Jace) shall be Tridium Vykon J-8200 at full 200 device license.
		2. The Building Network Controller (Jace) connects to the campus BMS VLAN IP network, serves as communications hub for local control units and has sufficient processor capabilities and RAM for advanced logic functions and sufficient storage space for trending, alarms, configuration, graphics, and reports as required.
		3. Include battery-backed uninterrupted real time clock capable of time of day, week and year information to the system as needed to perform software functions. Accuracy shall be within 1 second per day. The Building Network Controller (Jace) shall have the ability to perform all the following routines:
			1. Time-of-day scheduling
			2. Calendar-based scheduling
			3. Holiday scheduling
			4. Temporary schedule overrides
			5. Start-Stop Time Optimization
			6. Automatic Daylight Savings Time (DST) switch-over
			7. Night setback control
			8. Alarm Management
			9. Trending
		4. The Building Network Controller (Jace) shall be able to execute custom, job-specific processes defined by the user to automatically perform calculations and special control routines.
		5. Support firmware upgrades without the need to replace hardware.
		6. Global calculations (such as resets for cooling/heating demand) may be performed in the Building Network Controller (Jace).
		7. Building Network Controller (Jace) shall be configured to never exceed a CPU % of 70% for more than any 5 minutes period, as measured by the Station Resource Monitor. Prior to project acceptance, if the CPU % exceeds 70%, at no additional cost to Caltech, the Contractor shall install an additional Building Network Controller (Jace) or otherwise reconfigure the network as required to achieve a CPU % of less than 70% for any 5-minute period.
		8. Building Network Controller (Jace) shall be configured so the Used Heap shall never exceed 75% of the Max. Heap, as measured by the Station Resource Monitor. Prior to project acceptance, if the Used Heap exceeds 75% of the Max. Heap, the Building Network Controller (Jace) shall be considered overloaded and, at no additional cost to the Caltech, the Contractor shall install an additional Building Network Controller (JACE) or otherwise reconfigure the network as required to achieve a Used Heap that is less than 75% of the Max. Heap.
		9. Only services and/or modules published by Tridium or Distech may run in the Building Network Controller (Jace). Services and/or modules not published by Tridium or Distech require written approval from Caltech BMS Controls Shop to run in the Building Network Controller (Jace).
		10. Alarm extensions reside in the Building Network Controller (Jace) only. Alarms are forwarded to the Alarm Consoles in the Campus Supervisor Servers.
		11. Licensing
			1. Provide a complete set of product licenses for systems and third-party software used in system development, including documentation for all applications, databases, browsers, communications software etc.
			2. Caltech shall be the named license holder of all software.
			3. All Niagara 4 Station software licenses shall have the “accept.station.in=\*”; “accept.station.out=\*”; “accept.wb.in=\*” and “accept.wb.out=\*” section of the software licenses. Contractor shall ensure that the installed products are completely open for future integration, at no additional cost to Caltech.
			4. The license will include 5-year maintenance for software support and upgrades.
		12. Schedules reside in the Campus Supervisor for editing and viewing on graphics and should be imported into the Building Network Controller (Jace) for control processes.
		13. Route data from the Building Network Controller (Jace) to the Zone Controllers for such functions as:
			1. Point overrides
			2. Schedule commands
			3. Time synchronization
		14. All Building Network Controllers (Jace) and Niagara Server stations shall include the Haystack driver to enable open Haystack communications with other systems, including the Fault Detection Diagnostics platform.
		15. “Analytics system will be provided, installed and integrated to the BAS by the CxA. The controls contractor shall follow campus BAS standards and coordinate with the CxA as part of the commissioning process to ensure analytics can be integrated to the BAS efficiently and effectively.”
		16. Controls contractor shall be responsible to configure the BAS in such a way that enables the analytics system to integrate efficiently, which would minimally include:
			1. following Caltech’s control point naming standards
			2. following Caltech’s folder organization and naming conventions
			3. Installing and enabling the haystack service on each Niagara JACE
			4. Ensuring the Niagara JACEs and the device networks underneath them do not exceed resources capacity recommendations.
	5. BMS CONTROLLERs
		1. System controllers shall be Distech series controllers and if IP based controls are deployed shall have the following minimum requirements:
			1. BACnet communication protocol shall be used for all BAS manufacturer provided controllers (including terminal devices such as VAVs, FCUs, etc.)
			2. Support for IPv4 addressing
			3. DHCP support and Auto DNS
			4. Baud rate of not less than 100 Mbps
			5. 2 - RJ45 ports each capable of supporting 10/100 Base-T.
				1. Supporting controller daisy chaining on the Ethernet network via integral switch functionality.
				2. Integrated fail-safe should allow for communication when the controller is powered down.
			6. All controllers shall be able to communicate peer-to-peer without the need for a Network Control Unit (such as JACE, NAE, etc.) and shall be capable of assuming all responsibilities typically assumed by a Network Control Unit.
				1. Any controller on the Ethernet Data Link/Physical layer shall be able to act as a Master to allow for the exchange and sharing of data variables and messages with any other controller connected on the same communication cabling. Slave controllers are not acceptable.
				2. The resulting network will be a ‘Flat’ topology with all devices (controllers, workstations, …) connecting at the same physical network level
				3. Any software required for programming shall be unlicensed and openly available.
		2. System Controllers shall be utilized for the following applications:
			1. Air Handling Units
			2. Plenum Exhaust Fans
			3. Building Heating Hot Water Systems
			4. Building Chilled Water Systems
			5. Lighting Relays
		3. Miscellaneous controlled loads as defined by the plans and specifications.
		4. Provide approved I/O controller with remote input output modules to adequately cover all objects listed in the plans and specifications plus 20% spare capacity.
		5. Advanced programming ability shall include PID loops, time delay, schedules, battery-backed real-time clock, stage sequencing, logical gates, mathematical and comparator functions, psychometric functions, and persistent values.
		6. Inputs shall be software configurable for contact closure, resistance, 0-10VDC and 4-20 mA.
		7. Outputs shall include triac, relay (0-12 VDC), analog 0-10 VDC or 4-20 mA.
		8. All controllers shall interface to Building Network Controller (Jace) using BACnet protocol.
		9. Controller shall be equipped with a local keypad and display.
			1. Equip controller with local keypad and digital display for examination and editing data.
			2. Use of keypad and display shall require security password.
		10. Programming of System Controller shall be completely modifiable in the field over installed LANs or remotely using the campus BMS VLAN IP network.
	6. ZONE CONTROLLER
		1. Acceptable Zone Controller manufacturers shall be, Distech Controllers (or equal, prior approval required) if IP based controls are deployed shall have the following minimum requirements.
			1. BACnet communication protocol shall be used for all BAS manufacturer provided controllers (including terminal devices such as VAVs, FCUs, etc.)
			2. Support for IPv4 addressing
			3. DHCP support and Auto DNS
			4. Baud rate of not less than 100 Mbps
			5. 2 - RJ45 ports each capable of supporting 10/100 Base-T.
				1. Supporting controller daisy chaining on the Ethernet network via integral switch functionality.
				2. Integrated fail-safe should allow for communication when the controller is powered down.
			6. All controllers shall be able to communicate peer-to-peer without the need for a Network Control Unit (such as JACE, NAE, etc.) and shall be capable of assuming all responsibilities typically assumed by a Network Control Unit.
				1. Any controller on the Ethernet Data Link/Physical layer shall be able to act as a Master to allow for the exchange and sharing of data variables and messages with any other controller connected on the same communication cabling. Slave controllers are not acceptable.
				2. The resulting network will be a ‘Flat’ topology with all devices (controllers, workstations, …) connecting at the same physical network level
				3. Any software required for programming shall be unlicensed and openly available.
		2. Zone Controllers shall be utilized for the following applications.
			1. VAV / CAV Terminal Units
			2. Radiant Floor Zones
			3. Fan Coil
		3. Advanced customizable programming shall include PID loops, time delay, schedules, real-time clock, stage sequencing, logical gates, mathematical and comparator functions, psychometric functions, and persistent values.
		4. Inputs shall be software configurable for contact closure, resistance, 0-10VDC and 4-20 mA.
		5. Outputs shall include triac, relay (0-12 VDC), analog 0-10 VDC or 4-20 mA.
		6. The Zone Controller shall be BACnet BTL listed as an Application Specific Controller and Free Programmable Controller.
		7. For VAV applications a differential pressure sensor shall be provided integral to the controller for airflow measurement applications.
		8. Auto commissioning features shall be available for VAVs and FCUs to schedule automatic testing and record values (air flows, pressures, temperatures, etc.) for different operating modes. The auto commissioning feature shall be able to email reports and run commissioning on a specified schedule.
		9. Mount zone controller units outside of equipment and accessible for maintenance.
		10. Zone controllers shall provide sufficient internal memory for the specified control sequences and have at least 25 percent of the memory available for future use.
		11. Provide weather protection where required for control devices located outdoors. Include provisions for supplemental ventilation when control devices must be located within outdoor control panels.
		12. Programs and parameters shall be stored in nonvolatile memory.
		13. Programming of System Controller shall be completely modifiable in the field over installed LANs or remotely using the campus IP network.
	7. BMS THIRD PARTY CONTROLLER INTEGRATIONS
		1. Third Party Controllers refer to equipment controllers to be integrated to the BMS for the following applications including but not limited to:
			1. Variable Speed Drives (VFD’s)
			2. Air Flow Monitors
			3. Electrical Meters
			4. BTU Meters
		2. Controllers will be specified as LonWorks or BACnet wherever is appropriate for the building as recommended via email by Caltech controls shop. BACnet is acceptable for third party equipment provided with onboard controls. Provide a BACnet router for each trunk in this situation.
		3. Buildings with existing Lon Works infrastructure shall continue with LonWorks controllers & protocol.
		4. Final points list for third party integrated devices is the responsibility of the BMS provider and should be included in BMS submittal package for coordination and review by owner. The finished plan should act as a new record document for the
		5. Refer to BMS design drawing details for additional project specific data points.
		6.
	8. POWER SUPPLIES

		1. All AC and DC power supplies shall be rated at 125% of the anticipated power consumption and shall be fused with an integrated or DIN Frail mounted resettable circuit breaker.
		2. When selecting AC or DC power source for controllers, the manufacturer’s recommendation must be followed
	9. TEMPERATURE SENSORS
		1. Accuracy shall be ± 0.5 degrees Fahrenheit over the complete transmitter range.
		2. Major air system temperature sensors shall be a 10K type II thermistor type. Provide a conduit box for field wiring terminations. Averaging duct sensor shall be a flexible averaging probe appropriately sized for the equipment with a range of 20 to 120 degrees Fahrenheit.
		3. Immersion temperature sensors shall be a 10K type II thermistor type. Provide a stainless steel thermo well for installation by the Mechanical Contractor. Install the sensor in the thermo well with a heat conductive compound to insure accurate measurement. Provide a conduit box for field wiring terminations.
		4. Digital room thermostats shall be provided with display and configured for no local user adjustment unless otherwise specified. Provide after-hours override option. Where applicable, the setpoint adjustment may be software limited by the automation system to control the range of local room adjustment control. Locate thermostats as shown on the plans per ADA access requirements.
		5. Space temperature sensors shall be a 10K type II thermistor type, scaled for the range of the measured variable. Sensors shall have an enclosure that mounts on a 2 x 4 conduit box and will sense the ambient space air temperature. Sensors shall be located as shown on the plans or as required for proper space sensing.
		6. Terminal equipment controllers supply air temperature sensors shall be a 10K type II thermistor type, scaled for the range of the measured variable.
	10. HUMIDITY SENSORS
		1. The accuracy of space and duct sensors shall be ± 2% RH @ 77 degrees Fahrenheit within a range of 20% to 95% RH, including hysteresis, linearity, and repeatability.
		2. Room and duct sensors shall incorporate a temperature sensor in the same enclosure when required.
	11. WEATHER STATIONS FOR TEMPERATURE AND HUMIDITY
		1. Building weather shall have an integrated solar radiation shield. Accuracy shall be ± 2% RH @ 77 degrees Fahrenheit within a range of 20% to 95% RH, including hysteresis, linearity, and repeatability.
	12. PRESSURE SENSORS
		1. Differential pressure transmitters for hydronic systems shall utilize stainless steel transducers wired to a pressure transmitter with a digital display and remote sensing feature. Pipe taps shall be provided by the mechanical contractor as directed by the controls contractor to provide a representative system control pressure. The transmitter shall have a sensing accuracy of ± 1% over its full range, including hysteresis, linearity, and repeatability.
		2. Differential pressure transmitters for air systems shall include an LCD display and shall be mounted in the system control panel. The sensing tubes shall be extended to the point of measurement and terminated to provide a non-turbulent flow reading. The transmitter shall have a sensing accuracy of ± 1% over the full range, including hysteresis, linearity, and repeatability.
	13. CARBON DIOXIDE CO2 SENSORS
		1. Carbon dioxide sensors shall be mounted in the space at a level suitable for viewing, calibration, and servicing. CO2 measurement shall be a dual-wavelength, silicon-based NDIR sensor that does not require calibration for 5 years. The sensor transmitter shall have a minimum sensing accuracy of ± 2% over a range of 0 to 2000 PPM.
		2. The Air Monitoring System shall take precedence when specified and shall interface with the appropriate BMS controllers.
	14. CURRENT SWITCHES
		1. Current sensing switch shall be self-powered with solid-state circuitry and a dry contact output. A multi-turn setpoint adjustment shall set the trip point status. An LED shall indicate the on or off status.
	15. DAMPER ACTUATORS
		1. Actuators shall be direct mount type with a torque rating of 200% of the designed damper operating requirements. Provide integrated damper actuator end switches or feedback potentiometer where required for damper sequencing, positive position indication or control interlock wiring. The actuators shall have a de-clutching override to permit local manual damper operation without electric power and/or a control signal.
		2. Actuators shall be manufactured by Belimo (or equal, prior approval required).
		3. Laboratory supply and exhaust air valve actuators shall operate within two second for a setpoint change of 0 to 100% airflow. Fail safe mode shall be as indicated in the sequence of operation and be field selectable via dipswitches.
	16. AUTOMATIC CONTROL VALVES
		1. Control valves shall be normally closed unless specifically identified to be normally open with a spring-return actuator for critical process chilled water heat exchangers, OLAR facilities, Server rooms, or similar applications. The valve actuators shall have a de-clutching override to permit local manual operation without electric power and/or a control signal. Provide actuator with position indicator and feedback signal.
		2. Heating and cooling control valves up to 2 inches shall be modulating characterized type with a stainless-steel trim. The valve body shall be forged brass with female NPT threads and a 350 PSI pressure rating. Valves shall be able to close off against system pressures of 200 PSIG.
		3. Heating and cooling control valves 2 inches and larger shall be pressure independent control valves (Not Energy valve).
			1. Acceptable pressure independent control Valve manufacturers shall be, Belimo (or equal, prior approval required).
			2. Valves shall be able to close off against system pressures of 100 PSIG. The valve body shall be cast iron with 150 PSI flange connections. The valve shall have pressure ports for water balance flow measurement and able to be manually set to a design flow rate.
		4. Valves for outdoor installation shall have a NEMA 4 actuator. Weatherproof covers are not acceptable.
		5. Steam valves shall be proportioning type and rated for 200% of the inlet steam pressure. Valves shall be normally closed with a spring return actuator.
		6. Isolation control valves shall be 2-position line size butterfly type with cast iron body and flange connections. Valves shall be ANSI Class 150 with 285 PSI close-off at 100 degrees Fahrenheit. Valves shall have a NEMA 4X actuator with mechanical end switches that monitor the full open and the full closed position of the valve. Provide a hand wheel crank for manually positioning the valve. All Steam control valves shall be Class VI or better.
		7. Refer to control valve selection table for specific valve types and further information.
	17. BMS NETWORK SWITCHES
		1. All BMS network switches provided by the BMS controls contractor for building secondary IP network shall be managed switches.
		2. Switched port rules and security configuration is to be coordinated with Caltech BMS Controls Shop prior to deployment.
		3. Switch port rules shall be used to enforce switch ports allow traffic for only the necessary devices to prevent unnecessary traffic broadcasting.
	18. BMS CONTROL PANELS AND ENCLOSURES
		1. All BMS control panels and enclosures to be UL rated.
		2. All outdoor enclosure to be NEMA 4 rating at minimum.
		3. Provide appropriate NEMA rating where conditions would require enhanced NEMA ratings beyond the above stated ratings.
		4. BMS Building Network Controller control panels, (Jace cabinets) should be provided with locking mechanisms to match Caltech standard.

2.19 DDC CONTROL PANEL POWER SUPPLY

 A. Power supply transformer and other line-voltage equipment shall be located in a dedicated NEMA-3R rated enclosure outside of the DDC controller panel.

 B. Redundant power supply transformers shall be required for OLAR and other temperature-critical and Relative humidity-critical applications. The power supply failure shall trigger a BMS alarm.

PART 3 – EXECUTION

1. GENERAL
	* 1. Install control equipment and wiring in neat and workmanlike manner.
		2. Coordinate timely delivery of materials and coordinate activities of other trade contractors to install devices such as immersion wells, pressure tapings, any associated shut-off valves, flow switches, level switches, flow meters, air flow stations, valves, dampers, and other such items furnished by Control Contractor, which are to be installed by Mechanical Contractor.
		3. All BMS associated 120 VAC power wiring (including all input and output power supplies) shall originate from clearly marked, BMS-dedicated circuit breakers. All input/output transducers shall be powered from the same circuit that supplies power to the associated BMS controller. All BMS equipment shall be fused in accordance with manufacturer's recommendations.
		4. BMS controllers shall be labeled with the source of electrical power including panel number, circuit breaker number, and room number where electric panel is located, in accordance with the electrical labeling specification.
		5. Devices containing mercury are not allowed.
		6. Coordinate mounting height and location of control devices so that NEC workspace clearances are maintained.
2. PROJECT MANAGEMENT
	* 1. Provide a designated project manager who will be responsible for the following:
			1. Construct and maintain project schedule
			2. On-site coordination with all associated trades, Cx agent and other subcontractors
			3. Authorized to accept and execute orders or instructions from Caltech /AOR/ MEOR.
			4. Attend project meetings as scheduled by Caltech to avoid conflicts and delays
			5. Make necessary field decisions relating to this scope of work
			6. Advise Caltech regarding system designs may not achieve expected results or any other discrepancies
			7. Coordination/single point of contact
3. INSTALLATION
	* 1. All devices must be mounted in an accessible location for calibration, repair, or replacement and serviceable from a step ladder no taller than 8 feet. Due to unforeseen conditions if mounting is not accessible submit a RFI to address the issue.
		2. Space pressure measurement shall be averaged by utilizing one sensor reading a minimum of 3 different pickup locations distributed across the floors served by the AHU. The pickup points shall be in appropriate locations not influenced by airflow from a door, diffuser, or similar air movement to achieve a true average differential pressure indication.
		3. Document as-built conditions for any deviations from submitted plans.
		4. Install a local pressure gauge at each differential pressure control device. Built-in device LCD screens are acceptable. VAV and CAV boxes are excluded.
		5. All sensor and actuator instrumentation shall be hard wired to the controller the program is primarily executing. Instrumentation connected via a communications bus to VFDs are for monitoring only, primary executing functions shall be hard wired.
		6. Caltech will provide an IP communications interface to the campus fiber backbone including an Ethernet drop to the Niagara building Network Controller primary NIC port. All other BMS network communications required in the building shall be the responsibility of the Control’s Contractor.
		7. BMS performance issues associated with PICS conformance, such as timeouts, network speed issues or other, are the responsibility of the installing contractor to resolve. Third party integrated system PICS conformance, network issues are the responsibility of the equipment manufacturer.
		8. Coordinate final Building Network Controller locations prior to installation.
		9. Conform to the point device naming conventions furnished by Caltech. No deviation in naming convention will be accepted. New point names shall be submitted to Caltech BMS Controls Shop for approval prior to implementation.
4. DIGITAL CONTROLLERS
	* 1. Do not divide control of a single mechanical system such as supply/return/make-up air handling unit(s), boilers, chillers, or terminal equipment between two or more controllers. A single controller shall manage control functions for a single mechanical system.
		2. Provide stand-alone controllers. All I/O points for a single system shall be integral to one controller and its associated I/O expansion units. Performing equipment shall control without the need to communicate with any other controller or computer. Failure of any single device or control shall not cause a degradation of communications between the supervisor controller and any other digital controllers, nor shall it cause any other controller to fail. Outside temperature, humidity and calculated setpoints for optimization from BMS are exempt from this requirement.
		3. Locate system controllers as near as possible to controlled equipment.
		4. Provide local digital display for all controllers except for single zone mechanical systems and/or terminal units. External displays that are not integral to the controller shall be mounted inside control enclosure and shall be submitted to Caltech BMS Controls Shop for approval prior to implementation.
5. NAMEPLATES AND WIRE TAGS
	* 1. All HVAC equipment, controller cabinets, sensors, control devices, relays, etc. are to be labeled with a 3” wide by 1” high WHITE laminated plastic nameplates with BLACK lettering and a minimum of ¼” high engraved, capitalized block lettering backed with double sided adhesive. Laminated plastic shall be 1/8” thick with black center core.
		2. Each nameplate shall identify the system and object name as applicable, in accordance with Caltech Standard Naming Convention. HVAC equipment, controller cabinets shall be labeled using the system name of the HVAC system it is associated with in accordance with Caltech Standard Naming Convention.
		3. All physical I/O equipment devices (sensors, control devices, relays, etc.) shall be labeled using the object name of the I/O it is associated with in accordance with Caltech Standard Naming Convention.
		4. All physical I/O equipment devices (sensor, control devices, relays, etc.) not located within 5 feet of the associated HVAC equipment (such as supply air static pressure sensors, differential pressure sensors, relays, etc.) shall be labeled with both the system and object names. Nameplates shall be placed on or near the physical I/O equipment device and shall be placed in a visible location to aid in locating the device.
		5. Plastic nameplates for controllers and devices above the ceiling shall be mounted in a visible location (T-bar, wall adjacent to ceiling, etc.); controllers in enclosures located above drop ceilings shall require two nameplates. Prior approval is required for alternative methods of nameplate mounting.
		6. All control wiring shall be labeled at both terminations utilizing printed labels with the object name, in accordance with Caltech Standard Naming Convention, of the physical I/O equipment device with which it is associated, or the function it provides (24VAC, Network Communication, etc.)
		7. All controllers shall be properly labeled with the system name, and controller address, utilizing printed labels.
		8. All room temperature sensors shall be labeled with both the system name, object names, BACnet address, and if applicable, the system name of the primary system by which it is served) such as room temperature sensors associated with VAV boxes where multiple air handlers serve the building).
6. WIRING CRITERIA
	* 1. The contractor shall install control wiring as required to meet the project specifications, the National Electrical Code, National Electrical Safety Code, and all state and local codes. Unless specifically noted otherwise on the plans, Caltech requires the least expensive wiring installation that meets these specifications and codes within the following guidelines:
			1. In mechanical rooms and un-finished interior rooms, the wiring shall be run in EMT in exposed areas, unless noted otherwise.
			2. Under slab, in dirt or direct buried underground, schedule 40 PVC shall be used.
			3. Where subject to foot traffic or when cabling is run along roof surface, rigid conduit with threaded fittings shall be used.
			4. Whenever low voltage control cable is utilized without conduit, the low voltage control cable shall be plenum rated. Plenum rated cable shall be hung with bridle rings as required to prevent drooping. Laying of plenum rated cable on ceiling tiles for support is not allowed.
			5. Proper type of connectors shall be utilized where plenum rated cable enters equipment enclosures to secure and protect cables from damage.
			6. Whenever EMT conduit is attached to a vibrating surface, a short run of seal tight flexible conduit shall be utilized.
			7. Compression type fittings shall be used with EMT. Weatherproof compression type fittings shall be used with EMT in damp or wet locations. The use of setscrews is not permitted.
			8. Ground controllers and cabinets to an adequate earth grounding system. Grounding of the green AC ground wire, at the breaker panel, alone is not sufficient. Run metal conduit from controller panels to adequate building grounds. Ground sensors’ drain wire shields at controller end only.
			9. Contractor is responsible for correcting all associated ground loop problems.
			10. Splicing of control wire is prohibited. When slicing is not avoidable, wires shall terminate in an enclosure with terminal blocks with clear labeling. Location of the splicing enclosure shall be clearly shown and marked on as-build drawings.
7. SENSORS

	* 1. Provide temperature sensors in locations to sense the appropriate condition. Provide sensor where they are easy to access and service without special tools. Installation in dead spaces is not acceptable.
			1. Room Temperature Sensors: Install on interior walls to sense average room temperature conditions. Avoid locations near heat sources, supply air outlet drafts, locations where the sensor may be covered by office furniture, or where accurate room conditions may not be sensed. Sensor shall be isolated from drafts due to wall penetrations; conduit open to pressurized plenum with the use of manufacturer provided gaskets.
			2. Duct Temperature Sensors: Select specific sensor location within duct to accurately sense air temperatures. Do not locate sensors in dead air spaces or positions obstructed by ducts or equipment. Install gaskets between the sensor housing and duct wall. Seal duct and insulation penetrations.
				1. Furnish duct-averaging sensors where stratification is likely to occur, typically for large air ducts or in the mixing section of air handlers equipped with economizer.
				2. Flexible averaging sensors shall be supported maximum of every four feet between rigid supports by use of minimum radius temperature element bracket/holder mounting clips in serpentine position to sense average conditions. Proper thermally isolated temperature element supports shall be used. Using tape or tie wraps to support temperature element directly to rigid supports is not permitted.
			3. Immersion Temperature Sensors: Provide thermo-wells for sensors measuring temperatures in liquid applications or pressure vessels. Locate wells to sense continuous flow conditions. Wells shall not restrict flow area to less than 70 percent of pipe area.
			4. Outside Air Temperature Sensors: Install outside air temperature sensor on the north side of the building, away from exhaust hoods, air intakes, above building windows, doors, vents, dampers, and other areas that may affect temperature readings. The sensor should be mounted between four feet above the ground and one foot under the eave.
		2. Pressure Sensors: Install pressure sensing tips in locations to sense appropriate pressure conditions.
			1. Air handler static pressure sensor shall be installed two-thirds to three-quarters downstream of supply fan. Where there are multiple main branch ducts, there shall be a pressure sensor for each branch. Network sharing of duct static pressure for static pressure control is not allowed. Local system controller, controlling static pressure shall have hardwired sensor. Network sharing of remote static pressure for purpose of resetting and/or influencing local system control is acceptable.
			2. Hot water and chilled water loop differential pressure sensors shall be installed two-thirds to three-quarters downstream of supply pump. Where there are multiple main loops, there shall be a pressure sensor for each loop. Network sharing of loop differential pressure for pressure control is not allowed. Local system controller, controlling loop pressure shall have hardwired sensor. Network sharing of remote loop pressure for purpose of resetting and/or influencing local system control is acceptable.
		3. Flowmeters: Flowmeters shall be installed per manufacturers guidelines. Insertion type flowmeter must be installed in an accessible location for calibration, repair, or replacement and serviceable from a step ladder no taller than 8 feet. Due to unforeseen conditions if mounting is not accessible submit a RFI to address the issue.
8. CONTROL DRAWINGS
	* 1. Post laminated copies of compete as-built control system drawings in each mechanical room and in Supervisor controller cabinet. Post laminated copies of specific system’s as-built control drawings in the associated system controller cabinet.
9. SYSTEM START-UP
	* 1. Contractor is responsible for conducting comprehensive startup and checkout.
		2. Third party commissioning or functional testing shall not be used for the purposes of startup and checkout.
		3. Contractor to provide at a minimum the following startup task and associated documentation:
			1. Point to point checkout of all devices connected to a BMS controller. Including but not limited to sensors, actuators, relays, and VFDs.
			2. Verify proper scaling of control I/O signals between controller and devices.
			3. Contractor to verify all building systems operate per the submitted sequence of operation.
		4. All controls loops shall be tuned to deliver optimal stable setpoint control within the tolerances listed in 230900 section 1.11 B.
			1. Performance verification tests shall include verification that the control system maintains setpoints, system recovers properly following a power loss and control loops are tuned. System trends shall be utilized to track testing during one week of continuous HVAC and BMS systems operation.
			2. Trends should at minimum demonstrate stable operation with 15-minute sample intervals.
			3. Performance verification to demonstrate stable system performance shall be in accordance with prepared detail testing plans and procedures with CxA.
		5. The functional test for each HVAC system will be provided by the Controls Contractor and shall generally include but not be limited to:
			1. Orderly shutdown of the equipment from a local disconnects switch.
			2. Orderly restart of system operation when disconnect switch is returned to normal operation.
			3. Raise and lower each control setpoint 10% to witness a change in an expected time period.
			4. Manually stop primary fan, pump or heat exchanger and observe an automatic switchover to its backup unit.
			5. Force a demand control ventilation sequence mode.
			6. Force an economizer sequence mode.
			7. Force an unoccupied mode for zone reduced mode of operation.
			8. Simulate a sensed laboratory emergency for automatic safe operation.
			9. Other functional sequences to demonstrate compliance with all design intents.
10. TRAINING
	* 1. The controls contractor shall provide factory trained instructors with a minimum of 3 years’ experience to provide full instruction to Facilities Management personnel in the installation and sequence of operation installed. Instructors shall be thoroughly familiar with the specific system design intent and controls for which they are conducting to teach.
		2. Training shall take place only after project commissioning has been fully completed and systems are free of any punch-list issues and / or alarms. All training shall be held at Caltech during normal working hours of 7:00am to 3:30pm weekdays.
		3. Provide customer directed training for Caltech BMS Controls Shop operating engineers. Caltech shall approve proposed training agenda based on functional testing of each system for building operating engineers, prior to scheduled training. Sessions shall vary in time and will use the graphic system to demonstrate the functional operation of each primary, secondary, and unique zone system.
		4. The Contractor shall additionally provide training on the architecture of the system installed and its integration to the Caltech IP communications network. This training shall include BACnet point naming compliance with Caltech standards, alarms and user notifications, trends running and local operator interfaces.
		5. Provide 8 additional hours of training for post occupancy functional testing of system operation that could not be demonstrated because of the season.
11. RECORD DOCUMENTS
	* 1. Upon project completion, submit an operation manual consisting of the following and in accordance with Division 01 specifications:
			1. Index sheet, listing contents in alphabetical order.
			2. Manufacturer’s equipment parts list of all functional components of the system.
			3. Controller programs with comment description of sequence of operations
			4. List of connected data points, including panels to which they are connected and input/output devices (smoke detectors, sensors, actuators, etc.)
			5. Hardware points and virtual points commissioning document.
			6. Floor plan communications routing diagrams.
			7. Auto-CAD disk of as-built system schematics including all wiring diagrams.

**APPENDIX A**

Refer to current Caltech standards on-line for latest versions for the project. Included appendices are for reference only

**Caltech Asset and BMS Point Naming Standards:**

[https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards)

**APPENDIX B**

SAMPLE

**BMS NAMING AND TAGGING STANDARDS-REVISION 2.0**

Refer to current Caltech standards on-line for latest versions for the project.

**Caltech Asset and BMS Point Naming Standards:**

[https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards)

**APPENDIX C**

**BMS PROGRAMMING/GRAPHICS STANDARDS-REVISION 2.0**

Refer to current Caltech standards on-line for latest versions for the project. Included appendices are for reference only

**Caltech Asset and BMS Point Naming Standards:**

[https://facilitiesoperations.Caltech.edu/assetmanagement/namingstandards](https://facilitiesoperations.caltech.edu/assetmanagement/namingstandards)



