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1. DEFINITIONS & ABBREVIATION

1.1 **BACnet:** a Data Communications Protocol for Building Automation and Control Networks. It is defined by ASHRAE/ANSI Standard 135 (ISO 16484-5) standard protocol.

1.2 **DDC:** Direct digital control (DDC) is the automated control of a condition or process by a digital device (computer). DDC is often used to control the HVAC devices via microprocessors using software to perform the control logic. Such systems receive analog and digital inputs from the sensors and devices installed in the HVAC system and, according to the control logic, provide analog or digital outputs to control the HVAC system devices.

1.3 These systems may be mated with a software package that graphically allows operators to monitor, control, alarm and diagnose building equipment remotely.

1.4 **Ethernet:** Local area network, based on IEEE 802.3 standards.

1.5 **Firmware:** Software (programs or data) that has been written onto read-only memory (ROM). Firmware is a combination of software and hardware. Storage media with ROMs that have data or programs recorded on them are firmware.

1.6 **Gateway:** Bi-directional protocol translator connecting control systems that use different communication protocols.

1.7 **IP:** The Internet Protocol is the principal communications protocol in the Internet protocol suite for relaying datagrams across network boundaries. Its routing function enables internetworking, and essentially establishes the Internet.

1.8 **I/O:** Input/Output

1.9 **LAN:** Local area network.

1.10 **Modbus TCP/IP:** An open protocol for exchange of process data.

1.11 **Monitoring:** Acquisition, processing, communication, and display of equipment status data, metered electrical parameter values, power quality evaluation data, event and alarm signals, tabulated reports, and event logs.

1.12 **PoE:** Power over Ethernet describes standardized or ad-hoc systems which pass electrical power along with data on Ethernet cabling. This allows a single cable to provide both data connection and electrical power to devices such as wireless access points or IP cameras. Power may be carried on the same conductors as the data, or it may be carried on dedicated conductors in the same cable.

1.13 **RS-232:** A Telecommunications Industry Association standard for asynchronous serial data communications between terminal devices.

1.14 **RS-485:** A Telecommunications Industry Association standard for multipoint communications using two twisted-pairs.

1.15 **SCADA:** Supervisory Control And Data Acquisition is a type of industrial control system (ICS). Industrial control systems are computer controlled systems that monitor and control industrial processes that exist in the physical world.

1.16 T**hin Client:** A thin client is a computer or a computer program which depends heavily on some other computer (its server) to fulfill its computational roles.

2. CODES & STANDARDS

2.1 American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)

- ASHRAE Guide Guideline 13 – specifying DDC Systems
- ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings
- ASHRAE 135: BACnet - A Data Communication Protocol for Building Automation and Control Networks. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. current edition including all related addenda shall apply.

2.2 Electronics Industries Alliance

- EIA-709.1-A-99 Control Network Protocol Specification
- EIA-709.3-99: Free-Topology Twisted-Pair Channel Specification
- EIA-232: Interface between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange.
- EIA-458: Standard Optical Fiber Material Classes and Preferred Sizes
- EIA-485: Standard for Electrical Characteristics of Generator and Receivers for use in Balanced Digital Multipoint Systems.
- EIA-472: General and Sectional Specifications for Fiber Optic Cable
- EIA-475: Generic and Sectional Specifications for Fiber Optic Connectors and all Sectional Specifications
- EIA-573: Generic and Sectional Specifications for Field Portable Polishing Device for Preparation Optical Fiber and all Sectional Specifications
- EIA-590: Standard for Physical Location and Protection of Below-Ground Fiber Optic Cable Plant and all Sectional Specifications

2.3 Underwriters Laboratories

- UL 506 Specialty Transformers

- UL 508A Industrial Control Panels
- UL 916 Energy Management Systems.
- UL 1449 Surge Protective Devices

2.4 NEMA Compliance

- NEMA 250: Enclosure for Electrical Equipment
- NEMA ICS: General Standards for Industrial Controls.

2.5 NFPA/CSA Compliance

- NFPA 70 National Electrical Code (NEC)
- NFPA 72 National Fire Alarm and Signaling Code
- NFPA 90A Standard for the Installation of Air Conditioning and Ventilating Systems
- CSA C22.1 Canadian Electrical Code, CEC, Part 1, Safety Standard for Electrical Installations.
- OESC Ontario Electrical Safety Code

2.6 Institute of Electrical and Electronics Engineers (IEEE)

- IEEE 142: Recommended Practice for Grounding of Industrial and Commercial Power Systems
- IEEE 802.3: CSMA/CD (Ethernet - Based) LAN
- IEEE 802.4: Token Bus Working Group (ARCNET - Based) LAN

2.7 International Organization For Standardization (ISO)

- ISO 8802-3: Information Technology - Telecommunications and Information Exchange Between Systems

3. DESCRIPTION

3.1 **General**

3.1.1 The control system shall consist of a high-speed, peer-to-peer network of DDC controllers, a control system server, and a web-based operator interface.

3.1.2 System software shall be based on a server/thin client architecture, designed around the open standards of web technology. The control system server shall be accessed using a Web browser over the control system network, the owner's local area network, and (at the owner's discretion) over the Internet.

3.1.3 The intent of the thin-client architecture is to provide operators complete access to the control system via a Web browser. No special software other than a web browser shall

be required to access graphics, point displays, and trends, configure trends, configure points and controllers, or to download programming into the controllers.

3.1.4 System shall use the BACnet protocol for communication to the operator workstation or web server and for communication between control modules. I/O points, schedules, setpoints, trends and alarms.. System components shall communicate using native BACnet in accordance with ASHRAE Standard 135, including all workstations, all building controllers, and all application specific controllers. Gateways to other communication protocols are not acceptable.

3.1.5 The non-proprietary Web-based system shall host all related graphics and sequencing logic for monitoring and control.

3.1.6 The system shall be capable to communicate and transmit data over the network with the following systems:

3.1.6.1 CHUBB (status and remote control excluding CCTV)
3.1.6.2 Fire Alarm Systems
3.1.6.3 PA and Intercom Systems
3.1.6.4 Lighting Systems (status, lighting levels, remote control of dimming)
3.1.6.5 Power and Energy monitoring Tools
3.1.6.6 HVAC systems and environmental controls

3.1.7 All devices shall be TCP/IP addressable; IP/PoE automation platform is preferred.

3.1.8 The system shall have the ability to support bi-directional access to any remote field controller from anywhere on the network.

3.1.9 All system networks shall maintain a BUS topology; star network topologies shall not be accepted.

4. QUALITY ASSURANCE

4.1 Product Line Demonstrated History

4.1.1 The product line being proposed for the project must have an installed history of demonstrated satisfactory operation for a length of 2 years since date of final completion in at least 10 installations of comparative size and complexity. Submittals shall document this requirement with references.

4.2 Installer's Qualifications

4.2.1 Firms specializing and experienced with the installation of the the proposed product line installations for not less than 5 years. If installer is a Value Added Reseller (VAR) of a

manufacturer's product, installer must demonstrate at least three years prior experience with that manufacturer's products. Submittals must document this experience with references.

4.3 **Installer's Proximity**

4.3.1 Installer must maintain a fully capable service facility within a 60 km radius of the project site. Service facility shall manage the emergency service dispatches and maintain the inventory of spare parts.

5. EMERGENCY RESPONSE TIMES

5.1 **Emergency Service**

5.1.1 Any malfunction, failure, or defect in any hardware component or failure of any control programming that would result in property damage, loss of operational capability or comfort control.

5.1.2 Response by telephone to any request for emergency service shall be provided within two (2) hours of the Owner's initial telephone request for service.

5.1.3 In the event that the malfunction, failure, or defect is not corrected through the telephonic communication, at least one (1) hardware and software technician, trained in the system to be serviced, shall be dispatched to the Owner's site within eight (8) working hours of the initial telephone request for such services, as specified.

6. SYSTEM PERFORMANCE

6.1 **Performance Standards.**

6.1.1 System shall conform to the following minimum standards over network connections. Systems shall be tested using manufacturer’s recommended hardware and software for operator workstation (server and browser for web-based systems).

- Graphic Display: A graphic with 20 dynamic points shall display with current data within 10 sec.

- Graphic Refresh: A graphic with 20 dynamic points shall update with current data within 8 sec. and shall automatically refresh every 15 sec.

- Configuration Screens: Screens used for configuring, calibrating, or tuning points, PID loops, and similar control logic shall automatically refresh within 6 sec.

- Object Command: Devices shall react to command of a binary object within 2 sec. Devices shall begin reacting to command of an analog object within 2 sec.

- Alarm Response Time: An object that goes into alarm shall be annunciated at the workstation within 45 sec.

- Program Execution: Custom and standard applications shall be capable of running as often as once every 5 sec. Select execution times consistent with the mechanical process under control.

- Performance: Programmable controllers shall be able to completely execute DDC PID control loops at a frequency adjustable down to once per sec. Select execution times consistent with the mechanical process under control.

- Multiple Alarms: Each workstation on the network shall receive alarms within 5 sec of other workstations.

- Reporting Accuracy: System shall report values with minimum end-to-end accuracy listed in Table 1.
- Control Accuracy: Control loops shall maintain measured variable at setpoint within tolerances listed in Table 2.

Table-1 Reporting Accuracy

Measured Variable	Reported Accuracy
Space Temperature	±0.5ºC (±1ºF)
Ducted Air	±0.5ºC (±1ºF)
Outside Air	±1.0ºC (±2ºF)
Dew Point	±1.5ºC (±3ºF)
Water Temperature	±0.5ºC (±1ºF)
Delta-T	±0.15º (±0.25ºF)
Relative Humidity	±5% RH
Water Flow	±2% of full scale
Airflow (terminal)	±10% of full scale (see Note 1)
Airflow (measuring stations)	±5% of full scale
Airflow (pressurized spaces)	±3% of full scale
Air Pressure (ducts)	±25 Pa (±0.1 in. w.g.)
Air Pressure (space)	±3 Pa (±0.01 in. w.g.)
Water Pressure	±2% of full scale (see Note 2)
Electrical	±1% of reading (see Note 3)
Carbon Monoxide (CO)	±5% of reading
Carbon Dioxide (CO2)	±50 ppm

Table 2 Control Accuracy

Controlled	Control Accuracy	Range of Medium
Air Pressure	±50 Pa (±0.2 in. w.g.) ±3 Pa (±0.01 in. w.g.)	0–1.5 kPa (0–6 in. w.g.) -25 to 25 Pa (-0.1 to 0.1 in. w.g.)
Airflow	±10% of full scale	
Space	±1.0ºC (±2.0ºF)	
Duct	±1.5ºC (±3ºF)	
Humidity	±5% RH	
Fluid Pressure	±10 kPa (±1.5 psi) ±250 Pa (±1.0 in. w.g.)	MPa (1–150 psi) 0–12.5 kPa (0–50 in. w.g.)

7. PRODUCT DATA AND SHOP DRAWINGS SUBMISSION

7.1 Provide drawings as AutoCAD compatible files on optical disk (file format: .DWG, .DXF, or comparable) and three 11” x 17” prints of each drawing. When manufacturer’s cut sheets apply to a product series rather than a specific product, the data specifically applicable to the project shall be highlighted or clearly indicated by other means.

7.2 Each submitted piece of literature and drawing shall clearly reference the specification and/or drawing that the submittal is to cover. General catalogs shall not be accepted as cut sheets to fulfill submittal requirements.

7.3 Submit a BACnet Protocol Implementation Conformance Statement (PICS) for each submitted type of controller and operator interface.

7.4 Submittals shall include:

7.4.1 <u>DDC System Hardware</u>

7.4.1.1 A complete bill of materials to be used indicating quantity, manufacturer, model number, and relevant technical data of equipment to be used.

7.4.1.2 Manufacturer’s description and technical data such as performance curves, product specifications, and installation and maintenance instructions for items listed below and for relevant items not listed below:

- Direct digital controllers (controller panels)
- Transducers and transmitters
- Sensors (including accuracy data)
- Actuators
- Valves
- Relays and switches
- Control panels

- Power supplies
- Batteries
- Operator interface equipment
- Wiring

7.4.1.3 Wiring diagrams and layouts for each control panel. Show termination numbers.

7.4.1.4 Schematic diagrams for all field sensors and controllers. Provide floor plans of all sensor locations and control hardware. Riser diagrams showing control network layout, communication protocol, and wire types.

7.4.2 Central System Hardware and Software

7.4.2.1 A complete bill of material of equipment used indicating quantity, manufacturer, model number, and relevant technical information.

7.4.2.2 Manufacturer's description and technical data such as product specifications and installation and maintenance instructions for items listed below and for relevant items furnished under this contract not listed below:

- Central Processing Unit (CPU) or web server
- Monitors
- Keyboards
- Power supplies
- Battery backups
- Interface equipment between CPU or server and control panels
- Operating System software
- Operator interface software
- Color graphic software
- Third-party software

7.4.2.3 Schematic diagrams for all control, communication, and power wiring. Provide a schematic drawing of the central system installation. Label all cables and ports with computer manufacturers' model numbers and functions. Show interface wiring to control system.

7.4.2.4 Network riser diagrams of wiring between central control unit and control panels.

7.4.3 Controlled Systems

7.4.3.1 Riser diagrams showing control network layout, communication protocol, and wire types.

7.4.3.2 A schematic diagram of each controlled system. The schematics shall have all control points labeled with point names shown or listed. The schematics shall graphically show the location of all control elements in the system.

Typical graphical representation for a controlled system

7.4.3.3 A schematic wiring diagram of each controlled system. Label control elements and terminals. Where a control element is also shown on control system schematic, use the same name.

7.4.3.4 An instrumentation list (Bill of Materials) for each controlled system. List each control system element in a table. Show element name, type of device, manufacturer, model number, and product data sheet number.

7.4.3.5 A mounting, wiring, and routing plan-view drawing. The design shall take into account HVAC, electrical, and the design and elevation requirements of other systems (such as SCADA, lighting control, car counting system, building management system, etc). The drawing shall show the specific location of all concrete pads and bases and any special wall bracing for panels to accommodate this work.

7.4.3.6 A complete description of the operation of the control system, including sequences of operation. The description shall include and reference a schematic diagram of the controlled system.

7.4.3.7 A point list for each control system. List I/O points and software points specified. Indicate alarmed and trended points.

7.4.3.8 Quantities of items submitted shall be reviewed but are the responsibility of the Contractor.

7.4.3.9 Description of process, report formats, and checklists to be used

8. AS-BUILT AND CLOSE-OUT PROJECT DOCUMENTATION

8.1 Upon completion of installation, submit three copies of record (as-built) documents of the documents shall be submitted for approval prior to final completion and shall include:

8.1.1 Project Record Drawings. As-built versions of submittal shop drawings provided as AutoCAD compatible files on optical media (file format: .DWG, .DXF, or comparable) and as 11" x 17" prints.

8.1.2 Testing and Commissioning Reports and Checklists. Completed versions of reports, checklists, and trend logs used to meet requirements of Control System Demonstration and Acceptance section contained in this document

8.1.3 Operation and Maintenance (O&M) Manual including:

- Names, addresses, and telephone numbers of installing contractors and service representatives for equipment and control systems.
- Operator's manual with procedures for operating control systems: logging on and off, handling alarms, producing point reports, trending data, overriding computer control, and changing setpoints and variables.
- Programming manual or set of manuals with description of programming language and syntax, of statements for algorithms and calculations used, of point database creation and modification, of program creation and modification, and of editor use.
- Engineering, installation, and maintenance manual or set of manuals that explains how to design and install new points, panels, and other hardware; how to perform preventive maintenance and calibration; how to debug hardware problems; and how to repair or replace hardware.
- Documentation of programs created using custom programming language including setpoints, tuning parameters, and object database. Electronic copies of programs shall meet this requirement if control logic, setpoints, tuning parameters, and objects can be viewed using furnished programming tools.
- Graphic files, programs, and database on magnetic or optical media.

- List of recommended spare parts with part numbers and suppliers.
- Complete original-issue documentation, installation, and maintenance information for furnished third-party hardware including computer equipment and sensors.
- Complete original-issue copies of furnished software, including operating systems, custom programming language, operator workstation or web server software, and graphics software.
- Licenses, guarantees, and warranty documents for equipment and systems.
- Recommended preventive maintenance procedures for system components, including schedule of tasks such as inspection, cleaning, and calibration; time between tasks; and task descriptions.

9. WARRANTY

9.1 Warrant labor and materials for specified control system free from defects for a period of 24 months after final acceptance. Control system failures during warranty period shall be adjusted, repaired, or replaced at no additional cost or reduction in service to Owner. Respond during normal business hours within 24 hours of Owner's warranty service request.

9.2 Work shall have a single warranty date, even if Owner receives beneficial use due to early system start-up. If specified work is split into multiple contracts or a multi-phase contract, each contract or phase shall have a separate warranty start date and period.

9.3 Provide updates to operator workstation or web server software, project-specific software, graphic software, database software, and firmware that resolve the 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.

10. MAINTENANCE PLAN

10.1 Include a full service maintenance and monitoring plan for a period of 24 months after the system acceptance by the Owner. The FAS vendor shall coordinate web-access to the FAS and firewall security with Go Transit/Metrolinx.

10.2 The BAS vendor shall monitor the operation of the FAS system remotely and shall perform periodic checkups as described below.

10.3 Daily system check-ups by Web access:

10.3.1 Complete overall inspection to assure all equipment is operating and safety systems are in place

10.3.2 Verify in control software that schedules are accurate for the season, occupancy, etc.

10.3.3 Verify in control software that set points are accurate for season, occupancy, etc.

10.3.4 Exercise scan and command functions

10.3.5 Verify displays, printouts, and logs

10.3.6 Check displays of points in the system

10.3.7 Check error log

10.3.8 Test starts / stops, secure / access, test / reset, and alarm / return to normal

10.4 Monthly system check up by site visit:

10.4.1 Check all gauges to assure readings are correct

10.4.2 Calculate the amount of outside air introduced and compare to requirements

10.5 Semiannual checkup services by site visit:

10.5.1 Conduct a thorough check of all sensors, temperature, pressure, humidity, flow, etc for expected values and operation

10.5.2 Check for sensors accuracy and recalibrate where necessary. Perform all analysis, examinations, adjustments, and calibrations of all system equipment

10.5.3 Check and clean time clocks where applicable

10.5.4 Maintain all software integrity and shall detect and correct data file corruption

10.5.5 Provide a quarterly report of all maintenance actions to the Go Transit/Metrolinx Representative

10.5.6 Upgrade software when applicable and provide training for any software upgrades

11. OWNERSHIP OF PROPRIETARY MATERIAL

11.1 Project-specific software and documentation shall become Owner's property. This includes, but is not limited to:

- Graphics
- Record drawings
- Database
- Application programming code
- Documentation

12. COMMUNICATION

12.1 Control products, communication media, connectors, repeaters, hubs, and routers shall comprise a BACnet internetwork. Controller and operator interface communication shall conform to ANSI/ASHRAE Standard 135, BACnet.

12.2 Install new wiring and network devices as required to provide a complete and workable control network.

12.3 Each controller shall have a communication port for temporary connection to a laptop computer or other operator interface. Connection shall support memory downloads and other commissioning and troubleshooting operations.

12.4 Internetwork operator interface and value passing shall be transparent to internetwork architecture. An operator interface connected to a controller shall allow the operator to interface with each nternetwork controller as if directly connected. Controller information such as data, status, and control algorithms shall be viewable and editable from each internetwork controller.

12.5 Inputs, outputs, and control variables used to integrate control strategies across multiple controllers shall be readable by each controller on the internetwork. Program and test all cross-controller links required to execute control strategies specified in the sequences of operation. An authorized operator shall be able to edit cross-controller links by typing a standard object address or by using a point-and-click interface.

12.6 Workstations, Building Control Panels, and Controllers with real-time clocks shall use the BACnet Time Synchronization service. System shall automatically synchronize system clocks daily from an operator-designated device via the internetwork. The system shall automatically adjust for daylight saving and standard time as applicable.

12.7 System shall be expandable to at least twice the required input and output objects with additional controllers, associated devices, and wiring.

12.8 System shall support Web services data exchange with any other system that complies with XML (extensible markup language) and SOAP (simple object access protocol) standards specified by the Web Services Interoperability Organization(WS-I) Basic Profile 1.0 or higher. Web services support shall as a minimum be provided at the workstation or web server level and shall enable data to be read from or written to the system.

12.9 System shall support Web services read data requests by retrieving requested trend data or point values (I/O hardware points, analog value software points, or binary value software points) from any system controller or from the trend history database.

12.10 System shall support Web services write data request to each analog and binary object that can be edited through the system operator interface by downloading a numeric value to the specified object.

12.11 For read or write requests, the system shall require user name and password authentication and shall support SSL (Secure Socket Layer) or equivalent data encryption.

12.12 System shall support discovery through a Web services connection or shall provide a tool available through the Operator Interface that will reveal the path/identifier needed to allow a third party Web services device to read data from or write data to any object in the system which supports this service.

13. OPERATOR INTERFACE

13.1 The Operator Workstation or server shall conform to the BACnet Operator Workstation (B-OWS) or BACnet Advanced Workstation (B-AWS) device profile as specified in ASHRAE/ANSI 135 BACnet Annex L.

13.2 Operator Interface. Web server shall reside on high-speed network with building controllers. Each standard browser connected to server shall be able to access all system information.

13.3 Communication. Web server or workstation and controllers shall communicate using BACnet protocol. Web server or workstation and control network backbone shall communicate using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol and BACnet/IP addressing as specified in ANSI/ASHRAE 135, BACnet Annex J.

13.4 Each workstation or web server shall consist of the following:

13.4.1 Computer. Computer to be provided by Metrolinx I&IT and in accordance with DRM Appendix A – IT Telecommunication & Systems Document

13.4.2 Operating System. Operating System to be in accordance with DRM Appendix A – IT Telecommunication & Systems Document and to be confirmed prior to install. Currently, Microsoft Windows 7 Enterprise Service Pack 1.

13.4.3 System Graphics. The operator interface software shall be graphically based and shall include at least one graphic per piece of equipment or zone, and graphics that summarize conditions on each floor of each building. Indicate thermal comfort on floor plan summary graphics using dynamic colors to represent zone temperature relative to zone setpoint. Graphics shall allow operator to monitor system status, to view a summary of the most important data for each controlled zone or piece of equipment, to use point-and-click navigation between zones or equipment, and to edit setpoints and other specified parameters. Graphics shall be able to animate by displaying different image files for changed object status. Indicate areas or equipment in an alarm condition using color or other visual indicator. Graphics shall be saved in an industry-standard format such as BMP, JPEG, PNG, or GIF. Web-based system graphics shall be viewable on browsers compatible with World Wide Web Consortium browser

standards. Web graphic format shall require no plug-in (such as HTML and JavaScript) or shall only require widely available no-cost plug-ins (such as Active-X and Adobe Flash). Furnish a complete library of standard HVAC equipment graphics such as chillers, boilers, air handlers, terminals, fan coils, and unit ventilators, etc. This library also shall include standard symbols for other equipment including fans, pumps, coils, valves, piping, dampers, and ductwork. The library shall be furnished in a file format compatible with the graphics generation package program.

13.4.4 Automatic System Database Configuration. Each workstation or web server shall store on its hard disk a copy of the current system database, including controller firmware and software. Stored database shall be automatically updated with each system configuration or controller firmware or software change.

13.4.5 Manual Controller Memory Download. Operators shall be able to download memory from the system database to each controller.

13.4.6 On-Line Help. Provide a context-sensitive, on-line help system to assist the operator in operating and editing the system. On-line help shall be available for all applications and shall provide the relevant data for that particular screen. Additional help information shall be available through the use of hypertext.

13.4.7 Security. Each operator shall be required to log on to the system with user name and password in order to view, edit, add, or delete data. The user name and password combination of each user shall define accessible viewing, editing, adding, and deleting privileges for that operator. Users with system administrator rights shall be able to create new users and edit the privileges of all existing users. System Administrators shall also be able to vary and deny each operator's privileges based on the geographic location, such as the ability to edit operating parameters in Building A, to view but not edit parameters in Building B, and to not even see equipment in Building C. Automatically log out each operator if no keyboard or mouse activity is detected for more than 15 minutes. (this auto logoff time shall be user adjustable).

13.4.8 Encrypted Security Data. Store system security data including operator passwords in an encrypted format. System shall not display operator passwords.

13.4.9 System Diagnostics. The system shall automatically monitor the operation of all building management panels and controllers. The failure of any device shall be annunciated to the operator.

13.4.10 Alarm Processing. System input and status objects shall be configurable to alarm on departing from and on returning to normal state. Operator shall be able to enable or disable each alarm and to configure alarm limits, alarm limit differentials, alarm states, and alarm reactions for each system object. Alarms shall be BACnet alarm objects and shall use BACnet alarm services. Alarm messages shall use the English language descriptor for the object in alarm in such a way that the operator will be able to recognize the source, location, and nature of the alarm without relying on acronyms. Operator shall be able to configure (by object) what, if any actions are to be taken during an alarm. As a minimum, the workstation or web server shall be able to log,

print, start programs, display messages, send e-mail, send page, and audibly annunciate. Operators shall be able to view all system alarms and changes of state from any location in the system. Events shall be listed chronologically. An operator with the proper security level may acknowledge and delete alarms, and archive closed alarms to the workstation or web server hard disk.

13.4.11 Trend Logs. The operator shall be able to configure trend sample or change of value (COV) interval, start time, and stop time for each system data object and shall be able to retrieve data for use in spreadsheets and standard database programs. Controller shall sample and store trend data and shall be able to archive data to the hard disk. Trends shall be BACnet trend objects.

13.4.12 Object and Property Status and Control. Provide a method for the operator to view, and edit if applicable, the status of any object or property in the system. The status shall be available by menu, on graphics, or through custom programs.

13.4.13 Reports and Logs. Operator shall be able to select, to modify, to create, and to print reports and logs. Operator shall be able to store report data in a format accessible by standard spreadsheet and word processing programs.

14. STANDARD REPORTS.

14.1 Furnish the following standard system reports:

14.1.1 Objects. System objects and current values filtered by object type, by status (in alarm, locked, normal), by equipment, by geographic location, or by combination of filter criteria.

14.1.2 Alarm Summary. Current alarms and closed alarms. System shall retain closed alarms for an adjustable period.

14.1.3 Logs. System shall log the following to a database or text file and shall retain data for an adjustable period:

- Alarm History.
- Trend Data. Operator shall be able to select trends to be logged.
- Operator Activity. At a minimum, system shall log operator log in and log out, control parameter changes, schedule changes, and alarm acknowledgment and deletion. System shall date and time stamp logged activity.

15. ENERGY REPORTS

15.1 System shall include an easily configured energy reporting tool that provides the capabilities described in this section. The energy reporting tool shall be accessible

through the same user interface (Web browser or operator workstation software) as is used to manage the BAS. The energy reporting tool shall be preconfigured to gather and store energy demand and consumption data from each energy source that provides metered data to the BAS. Meter data shall be stored at 5 minute intervals unless otherwise specified in the Sequence of Operation provided in section 23 09 93. This data shall be maintained in an industry standard SQL database for a period of not less than five years.

15.2 The energy reporting tool shall allow the operator to select an energy source and a time period of interest (day, week, month, year, or date range) and shall provide options to view the data in a table, line graph, bar graph, or pie chart. The tool shall also allow the operator to select two or more data sources and display a comparison of the energy used over this period in any of the listed graph formats, or to total the energy used by the selected sources and display that data in the supported formats.

15.3 The energy reporting tool shall record on-peak, mid-peak, off-peak, summer and winter energy usage, with associated time of use rates.

15.4 The energy reporting tool shall allow the operator to select and energy source and up to twelve time periods of interest (day, week, month, year, or date range) and display a graph that compares the energy use over the two time periods in any of the graph formats listed in the previous paragraph. The tool shall also allow the operator to select multiple energy sources and display a graph that compares the total energy used by these sources over the two time periods.

15.5 The energy reporting tool shall allow the operator to easily generate the previously described graphs "on the fly," and shall provide an option to store the report format so the operator can select that format to regenerate the graph at a future date. The tool shall also allow the user to schedule these reports to run on a recurring basis using relative time periods, such as automatically generating a consumption report on the first Monday of each month showing consumption over the previous month. Automatically generated reports shall be archived on the server in a common industry format such as Adobe PDF or Microsoft Excel with copies e-mailed to a user editable list of recipients.

15.6 The energy reporting tool shall be capable of collecting and displaying data from the following types of meters:

15.6.1 Electricity
15.6.2 Gas
15.6.3 Chilled Water
15.6.4 Potable Water
15.6.5 Heating and cooling degree days. (May be calculated from sensor data rather than metered.)

15.7 The energy reporting tool shall include provisions for future additions and expansions, with up to 30% spare capacity.

15.8 The user shall have the option of entering benchmark data for an individual facility or a group of facilities.

15.9 The user shall have the option of displaying any or all of the following data on any chart, line, or bar graph generated by the energy reporting tool:

15.9.1 Low/High/Average value of the metered value being displayed.
15.9.2 Peak demand kW, kVA
15.9.3 Capable of collecting and displaying from SCADA parameters information such as Voltage, Hz, PF (power factor), Amps, kW, kVA, kVAR.
15.9.4 Heating and/or Cooling Degree Days for the time period(s) being displayed.

16. WORKSTATION APPLICATION EDITORS

16.1 Each PC or browser workstation shall support editing of all system applications. The applications shall be downloaded and executed at one or more of the controller panels.

16.2 Controller. Provide a full-screen editor for each type of application that shall allow the operator to view and change the configuration, name, control parameters, and set points for all controllers.

16.3 Scheduling. An editor for the scheduling application shall be provided at each workstation. Provide a method of selecting the desired schedule and schedule type. Exception schedules and holidays shall be shown clearly on the calendar. The start and stop times for each object shall be adjustable from this interface.

16.4 Custom Application Programming. Provide the tools to create, edit, debug, and download custom programs. System shall be fully operable while custom programs are edited, compiled, and downloaded. Programming language shall have the following features:

16.4.1 Language. Language shall be graphically based and shall use function blocks arranged in a logic diagram that clearly shows control logic flow. Function blocks shall directly provide functions listed below, and operators shall be able to create custom or compound function blocks.

16.4.2 Programming Environment. Tool shall provide a full-screen, cursor-and-mouse-driven programming environment that incorporates word processing features such as cut and paste. Operators shall be able to insert, add, modify, and delete custom programming code, and to copy blocks of code to a file library for reuse in other control programs.

16.4.3 Debugging and Simulation. Operator shall be able to step through the program observing intermediate values and results. Operator shall be able to adjust input variables to simulate actual operating conditions. Operator shall be able to adjust each step's time increment to observe operation of delays, integrators, and other time-sensitive control logic. Debugger shall provide error messages for syntax and for execution errors.

16.4.4 Conditional Statements. Operator shall be able to program conditional logic using compound Boolean (AND, OR, and NOT) and relational (EQUAL, LESS THAN, GREATER THAN, NOT EQUAL) comparisons.

16.4.5 Mathematical Functions. Language shall support floating-point addition, subtraction, multiplication, division, and square root operations, as well as absolute value calculation and programmatic selection of minimum and maximum values from a list of values.

16.4.6 Variables. Operator shall be able to use variable values in program conditional statements and mathematical functions.

16.4.7 Time Variables. Operator shall be able to use predefined variables to represent time of day, day of the week, month of the year, and date. Other predefined variables or simple control logic shall provide elapsed time in seconds, minutes, hours, and days. Operator shall be able to start, stop, and reset elapsed time variables using the program language.

16.4.8 System Variables. Operator shall be able to use predefined variables to represent status and results of Controller Software and shall be able to enable, disable, and change setpoints of Controller Software as described in Controller Software section.

16.4.9 Portable Operator's Terminal. Provide all necessary software to configure an IBM-compatible laptop computer for use as a Portable Operator's Terminal. Operator shall be able to connect configured Terminal to the system network or directly to each controller for programming, setting up, and troubleshooting.

17. CONTROLLER SOFTWARE

17.1 Furnish the following applications for building and energy management. All software application shall reside and operate in the system controllers. Applications shall be editable through operator workstation, web browser interface, or engineering workstation.

17.1.1 Scheduling. Provide the capability to execute control functions according to a user created or edited schedule.

17.1.2 System Coordination. Operator shall be able to group related equipment based on function and location and to use these groups for scheduling and other applications.

17.1.3 Binary Alarms. Each binary object shall have the capability to be configured to alarm based on the operator-specified state. Provide the capability to automatically and manually disable alarming.

17.1.4 Analog Alarms. Each analog object shall have both high and low alarm limits. The operator shall be able to enable or disable these alarms.

17.1.5 Alarm Reporting. The operator shall be able to determine the action to be taken in the event of an alarm. An alarm shall be able to start programs, print, be logged in the event log, generate custom messages, and display on graphics.

17.1.6 Remote Communication. System shall automatically contact operator workstation or server on receipt of critical alarms. If no network connection is available, system shall use a modem connection.

17.1.7 Maintenance Management. The system shall be capable of generating maintenance alarms when equipment exceeds adjustable runtime, equipment starts, or performance limits.

17.1.8 Sequencing. Application software shall sequence all equipment as specified in the contract documents

17.1.9 PID Control. System shall provide direct- and reverse-acting PID (proportional-integral-derivative) algorithms. Each algorithm shall have anti-windup and selectable controlled variable, setpoint, and PID gains. Each algorithm shall calculate a time-varying analog value that can be used to position an output or to stage a series of outputs. The calculation interval, PID gains, and other tuning parameters shall be adjustable by a user with the correct security level.

17.1.10 Staggered Start. System shall stagger controlled equipment restart after power outage. Operator shall be able to adjust equipment restart order and time delay between equipment restarts.

18. ENERGY CALCULATIONS.

18.1 The system shall accumulate and convert instantaneous power (kW) or flow rates (L/s [gpm]) to energy usage data. The system shall calculate a sliding-window average (rolling average). Operator shall be able to adjust window interval to 15 minutes, 30 minutes, or 60 minutes.

18.2 Provide software to totalize runtime for each binary input and output. Operator shall be able to enable runtime alarm based on exceeded adjustable runtime limit. Configure and enable runtime totalization and alarms as specified in Section 23 09 93 (Sequence of Operations).

19. CONTROLLERS

19.1 Provide an adequate number of Building Controllers (BC), Advanced Application Controllers (AAC), Application Specific Controllers (ASC), Smart Actuators (SA), and Smart Sensors (SS) as required to achieve performance specified in the contract documents. Every device in the system which executes control logic and directly controls HVAC equipment must conform to a standard BACnet Device profile as specified in ANSI/ASHRAE 135, BACnet Annex L. Unless otherwise specified, hardwired actuators and sensors may be used in lieu of BACnet Smart Actuators and Smart Sensors.

19.1.1 Building Controllers (BCs). Each BC shall conform to BACnet Building Controller (B-BC) device profile as specified in ANSI/ASHRAE 135, BACnet Annex L, and shall be listed as a certified B-BC in the BACnet Testing Laboratories (BTL) Product Listing.

19.1.2 Advanced Application Controllers (AACs). Each AAC shall conform to BACnet Advanced Application Controller (B-AAC) device profile as specified in ANSI/ASHRAE 135, BACnet Annex L and shall be listed as a certified B-AAC in the BACnet Testing Laboratories (BTL) Product Listing.

19.1.3 Application Specific Controllers (ASCs). Each ASC shall conform to BACnet Application Specific Controller (B-ASC) device profile as specified in ANSI/ASHRAE 135, BACnet Annex L and shall be listed as a certified B-ASC in the BACnet Testing Laboratories (BTL) Product Listing.

19.1.4 Smart Sensors (SSs). Each SS shall conform to BACnet Smart Sensor (B-SS) device profile as specified in ANSI/ASHRAE 135, BACnet Annex L and shall be listed as a certified B-SS in the BACnet Testing Laboratories (BTL) Product Listing.

20. BACNET COMMUNICATION.

20.1 Each BC shall reside on or be connected to a BACnet network using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol and BACnet/IP addressing. BACnet routing shall be performed by BCs or other BACnet device routers as necessary to connect BCs to networks of AACs and ASCs.

20.2 Each AAC shall reside on a BACnet network using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol with BACnet/IP addressing, or it shall reside on a BACnet network using the ARCNET or MS/TP Data Link/Physical layer protocol.

20.3 Each ASC shall reside on a BACnet network using the ARCNET or MS/TP Data Link/Physical layer protocol.

20.4 Each SS shall reside on a BACnet network using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol with BACnet/IP addressing, or it shall reside on a BACnet network using ARCNET or MS/TP Data Link/Physical layer protocol.

20.5 Each controller shall provide a service communication port for connection to a Portable Operator's Terminal. Connection shall be extended to space temperature sensor ports where shown on drawings.

20.6 BC and ASC operating systems shall manage input and output communication signals to allow distributed controllers to share real and virtual object information and to allow for central monitoring and alarms.

20.7 Each BC and AAC shall share data as required with each networked BC and AAC.

21. STAND-ALONE OPERATION.

21.1 Each piece of equipment shall be controlled by a single controller to provide stand-alone control in the event of communication failure. All I/O points specified for a piece of equipment shall be integral to its controller. Provide stable and reliable stand-alone control using default values or other method for values normally read over the network such as outdoor air conditions, supply air or water temperature coming from source equipment, etc.

21.2 Controller hardware shall be suitable for anticipated ambient conditions. Controllers used outdoors or in wet ambient conditions shall be mounted in waterproof enclosures and shall be rated for operation at -29°C to 60°C (-20°F to 140°F).Controllers used in conditioned space shall be mounted in dust-protective enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

21.3 Provide a local keypad and display for each BC and AAC. Operator shall be able to use keypad to view and edit data. Keypad and display shall require password to prevent unauthorized use. If the manufacturer does not normally provide a keypad and display for each BC and AAC, provide the software and any interface cabling needed to use a laptop computer as a Portable Operator's Terminal for the system.

21.4 Controllers that perform scheduling shall have a real-time clock.

21.5 Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to a field-removable modular terminal strip or to a termination card connected by a ribbon cable. Each BC and AAC shall continually check its processor and memory circuit status and shall generate an alarm on abnormal operation. System shall continuously check controller network and generate alarm for each controller that fails to respond.

22. MEMORY.

22.1 Controller memory shall support operating system, database, and programming requirements. Each BC and AAC shall retain BIOS and application programming for at least 72 hours in the event of power loss.

22.2 Each ASC and SA shall use nonvolatile memory and shall retain BIOS and application programming in the event of power loss. System shall automatically download dynamic control parameters following power loss.

22.3 Controllers shall be able to operate at 90% to 110% of nominal voltage rating and shall perform an orderly shutdown below 80% nominal voltage. Operation shall be protected against electrical noise of 5 to 120 Hz and from keyed radios up to 5 W at 1 m (3 ft).

22.4 ASC power supply shall be fused or current limiting and shall be rated at a minimum of 125% of ASC power consumption.

23. INPUT AND OUTPUT INTERFACE

23.1 Hard-wire input and output points to BCs, AACs, ASCs, or SAs.

23.2 Protection.

23.2.1 All input points and output points shall be protected such that shorting of the point to itself, to another point, or to ground shall cause no damage to the controller. All input and output points shall be protected from voltage up to 24 V of any duration, such that contact with this voltage will cause no controller damage.

23.3 Binary Inputs.

23.3.1 Binary inputs shall allow the monitoring of ON/OFF signals from remote devices. The binary inputs shall provide a wetting current of at least 12 mA to be compatible with commonly available control devices and shall be protected against contact bounce and noise. Binary inputs shall sense dry contact closure without application of power external to the controller.

23.4 Pulse Accumulation Inputs.

23.4.1 Pulse accumulation inputs shall conform to binary input requirements and shall also accumulate up to 10 pulses per second.

23.5 Analog Inputs.

23.5.1 Analog inputs shall monitor low-voltage (0–10 Vdc), current (4–20 mA), or resistance (thermistor or RTD) signals. Analog inputs shall be compatible with and field configurable to commonly available sensing devices.

23.6 Binary Outputs.

23.6.1 Binary outputs shall provide for ON/OFF operation or a pulsed low-voltage signal for pulse width modulation control. Binary outputs on Building Controllers shall have three-position (on-off-auto) override switches and status lights. Outputs shall be selectable for normally open or normally closed operation.

23.7 Analog Outputs.

23.7.1 Analog outputs shall provide a modulating signal for the control of end devices. Outputs shall provide either a 0–10 Vdc or a 4–20 mA signal as required to properly control output devices. Each Building Controller analog output shall have a two-position (auto-manual) switch, a manually adjustable potentiometer, and status lights. Analog outputs shall not drift more than 0.4% of range annually.

23.8 Tri-State Outputs.

23.8.1 Control three-point floating electronic actuators without feedback with tri-state outputs (two coordinated binary outputs). Tri-State outputs may be used to provide analog output control in zone control and terminal unit control applications such as VAV terminal units, duct-mounted heating coils, and zone dampers.

23.9 System Object Capacity.

23.9.1 The system size shall be expandable to at least twice the number of input/ output objects required for this project. Additional controllers (along with associated devices and wiring) shall be all that is necessary to achieve this capacity requirement. The operator interfaces installed for this project shall not require any hardware additions or software revisions in order to expand the system

24. POWER SUPPLIES AND LINE FILTERING

24.1 Control transformers shall be ULC listed and in full compliance with the requirements of OESC (Ontario Electrical safety Code). Furnish listed current-limiting type or furnish over-current protection in primary and secondary circuits n accordance with OESC requirements. Limit connected loads to 80% of rated capacity.

24.2 DC power supply output shall match output current and voltage requirements. Unit shall be full-wave rectifier type with output ripple of 5.0 mV maximum peak-to-peak. Regulation shall be 1.0% line and load combined, with 100-microsecond response time for 50% load changes. Unit shall have built-in over-voltage and over-current protection and shall be able to withstand 150% current overload for at least three seconds without trip-out or failure.

24.3 Unit shall operate between 0°C and 50°C (32°F and 120°F). EM/RF shall meet FCC Class B and VDE 0871 for Class B and MILSTD 810C for shock and vibration.

24.4 Line voltage units shall be ULC recognized and CSA listed.

24.5 Provide internal or external transient voltage and surge suppression for workstations and controllers. Surge protection shall have:

24.5.1 Dielectric strength of 1000 V minimum

24.5.2 Response time of 10 nanoseconds or less

24.5.3 Transverse mode noise attenuation of 65 dB or greater

24.5.4 Common mode noise attenuation of 150 dB or greater at 40–100 Hz

25. AUXILIARY CONTROL DEVICES

25.1 **Motorized Control Dampers**.

25.1.1.1 Type. Control dampers shall be the parallel or opposed-blade type as specified herein:

- All modulating dampers shall be opposed blade type.
- All ON/OFF dampers shall be parallel blade type.
- All outdoor air dampers and exhaust air dampers shall be double wall construction, insulated, ultra low-leak construction

25.1.1.2 Frame. Damper frames shall be 2.38 mm (13 gauge) galvanized steel channel or 3.175 mm (⅛ in.) extruded aluminum with reinforced corner bracing.

25.1.2 Blades. Damper blades shall not exceed 20 cm (8 in.) in width or 125 cm (48 in.) in length. Blades shall be suitable for medium velocity (10 m/s [2000 fpm]) performance. Blades shall be not less than 1.5875 mm (16 gauge).

25.1.3 Shaft Bearings. Damper shaft bearings shall be as recommended by manufacturer for application, oil impregnated sintered bronze, or better.

25.1.4 Seals. Blade edges and frame top and bottom shall have replaceable seals of butyl rubber or neoprene. Side seals shall be spring-loaded stainless steel. Blade seals shall leak no more than 50 L/s•m^2(10 cfm per ft^2) at 1000 Pa (4 in. w.g.) differential pressure. Blades shall be airfoil type suitable for wide-open face velocity of 7.5 m/s (1500 fpm).

25.1.5 Sections. Individual damper sections shall not exceed 125 cm × 150 cm (48 in. × 60 in.). Each section shall have at least one damper actuator. Modulating dampers shall provide a linear flow characteristic where possible.

25.1.6 Linkages. Dampers shall have exposed linkages.

25.2 **Electric Damper and Valve Actuators**.

25.2.1 Stall Protection. Mechanical or electronic stall protection shall prevent actuator damage throughout the actuator's rotation.

25.2.2 Spring-return Mechanism. Actuators used for power-failure and safety applications shall have an internal mechanical spring-return mechanism or an uninterruptible power supply (UPS).

25.2.3 Signal and Range. Proportional actuators shall accept a 0–10 Vdc or a 0–20 mA control signal and shall have a 2–10 Vdc or 4–20 mA operating range.

25.2.4 Wiring. 24 Vac and 24 Vdc actuators shall operate on Class 2 wiring.

25.2.5 Manual Positioning. Operators shall be able to manually position each actuator when the actuator is not powered. Non-spring-return actuators shall have an external manual gear release. Spring-return actuators with more than 7 N•m (60 in.-lb) torque capacity shall have a manual crank.

25.3 **Control Valves**.

25.3.1 Control valves shall be two-way or three-way type for two-position or modulating service.

25.3.2 Close-off (differential) Pressure Rating: Valve actuator and trim shall be furnished to provide the following minimum close-off pressure ratings:

25.3.2.1 Water Valves:

- Two-way: 150% of total system (pump) head.
- Three-way: 300% of pressure differential between ports A and B at design flow or 100% of total system (pump) head.
- Max. pressure drop across the control valve: 3 psi (20.7 kPa)

25.3.2.2 Steam Valves:

- 150% of operating (inlet) pressure.
- Max. pressure drop: 25% of inlet pressure.

25.3.3 Control Valves Construction

25.3.3.1 Automatic control valves, unless otherwise specified, shall be globe type valves. The use of ball valves in sizes 1½" (40mm) and smaller shall also be acceptable. Valves and actuators shall be ordered as one factory-assembled and tested unit.

25.3.3.2 Valves 2" (50mm) and smaller shall be constructed of bronze. Valves 2 ½" (65mm) and larger shall have iron bodies and bronze mountings.

25.3.3.3 All control valves shall have stainless steel stems. Ball valves shall be equipped with stainless steel balls and stems.

25.3.3.4 The bronze in bodies and bonnets of all bronze valves shall conform to ASTM B62 for valves rated up to 150psig (1035 Kpa) working pressure and to ASTM B61 for valves rated at 200 psig (1380 Kpa) working pressure.

25.3.3.5 The bodies and bonnets of iron body valves shall conform to ASTM A126, Class B.

25.3.3.6 Control valve discs and seats shall be of bronze for 100 °C or less fluid temperature and of stainless steel for fluid temperatures above 100 °C.

25.3.3.7 The control valves shall have tight shut-off. Flat disk valves are not acceptable.

25.3.3.8 Control valves 2" (50mm) and smaller shall be complete with screwed ends type, except for bronze valves installed in soldered copper piping which shall be complete with soldering ends. Control valves larger than 2" (50mm) shall be complete with flanged end type and proper flanged adapters to copper shall be provided where flanged valves are installed in copper piping.

25.3.3.9 Each automatic control valve must provide the design output and flow rates at pressure drops compatible with equipment selected. Each automatic control valve must be suitable for the particular system working pressure.

25.3.3.10 Each automatic control valve shall be fitted with a position indicator.

25.3.3.11 All the same type control valves shall be the products of a single manufacturer and have the manufacturer's name, pressure rating and size clearly marked on the outside of the body.

25.3.3.12 Unless otherwise indicated and except the steam zone control valves, control valves for proportional operation shall have equal percentage characteristics, while the control valves for open/shut two-position operation shall have straight line flow characteristics.

25.3.3.13 The zone steam control valves shall have linear characteristics.

25.3.3.14 Heating valves shall be normally open and cooling valves are to be normally closed, unless otherwise specified.

25.4 **Thermostats**

25.4.1 Low-Voltage Space Thermostats. Low-voltage space thermostats shall be 24 V, bimetal-operated, mercury-switch type, with adjustable or fixed anticipation heater, concealed

setpoint adjustment, 13°C–30°C (55°F–85°F) setpoint range, 1°C (2°F) maximum differential, and vented ABS plastic cover.

25.4.2 Line-Voltage Space Thermostats. Line-voltage space thermostats shall be bimetal-actuated, open-contact type or bellows-actuated, enclosed, snap-switch type or equivalent solid-state type, with heat anticipator, UL listing for electrical rating, concealed setpoint adjustment, 13°C–30°C (55°F–85°F) setpoint range, 1°C (2°F) maximum differential, and vented ABS plastic cover.

25.4.3 Low-Limit Thermostats. Low-limit airstream thermostats shall be UL listed, vapor pressure type. Element shall be at least 6 m (20 ft) long. Element shall sense temperature in each 30 cm (1 ft) section and shall respond to lowest sensed temperature. Low-limit thermostat shall be manual reset only.

25.5 **Thermostat Guards**

25.5.1 Provide a heavy duty, metal thermostat guard for specified existing, stand-alone thermostats.

25.5.2 The guard shall be have a minimum 18 guage metal cover and 22 guage ring base. The unit shall be tamper-resistant and equipped with a lock and key. The colour of the unit shall be beige.

25.6 **Temperature Sensors**.

25.6.1 Type. Temperature sensors shall be Resistance Temperature Device (RTD) or thermistor.

25.6.2 Duct Sensors. Duct sensors shall be single point or averaging as shown. Averaging sensors shall be a minimum of 1.5 m (5 ft) in length per 1 m2(10 ft2) of duct cross-section.

25.6.3 Immersion Sensors. Provide immersion sensors with a separable stainless steel well. Well pressure rating shall be consistent with system pressure it will be immersed in. Well shall withstand pipe design flow velocities.

25.6.4 Space Sensors. Space sensors shall have local +/-2 deg.C setpoint adjustment, override switch, display, and communication port.

25.6.5 Differential Sensors. Provide matched sensors for differential temperature measurement.

25.7 **Snow Melting/Slab Sensors**

25.7.1 Snow Melting / Slab Sensor requirements are included in the Snow Melting DRM document.

25.8 **Humidity Sensors.**

25.8.1 Duct and room sensors shall have a sensing range of 20%–80%.

25.8.2 Duct sensors shall have a sampling chamber.

25.8.3 Outdoor air humidity sensors shall have a sensing range of 20%–95% RH and shall be suitable for ambient conditions of -40°C–75°C (-40°F–170°F).

25.8.4 Humidity sensors shall not drift more than 1% of full scale annually.

25.9 **Liquid and Steam Pressure Transmitters**

25.9.1 Provide liquid and steam pressure transmitters with the following minimum characteristics:

25.9.1.1 Minimum pressure operating range from 0 – 60 psi over 0-85 degrees C ambient/medium temperature range, for the liquid type.

25.9.1.2 Minimum pressure operating range from 0 – 30 psi over 0-85 degrees C ambient/medium temperature range, for the steam type.

25.9.1.3 End-to-end accuracy of +/- 1% of operating pressure range over 0-85 degrees C ambient/medium temperature range.

25.9.1.4

25.9.1.5 Wetted parts shall be stainless steel 316L complete with SS304 for the case.

25.9.1.6 4-20mA output

25.9.1.7 Provide a pressure gauge (Winters, 5” diameter min.) of the same range as the transducer. The tap point(s) for the gauge shall be the same as those used by the pressure transducer and the gauge shall be installed adjacent to the transducer. For single pressure applications, provide a manual shut-off valve. For differential pressure applications, provide manual shut-off valves for the high and low side lines so that the gauge can display either pressure.

25.10 **Air Static Pressure Transmitter**

25.10.1 Provide air pressure transmitters with the following minimum characteristics:

25.10.1.1 Solid State design.

25.10.1.2 Operating on capacitance principle.

25.10.1.3 With non-interactive fine resolution zero and span adjustments.

25.10.1.4 End-to-end accuracy +/- 1% of full scale pressure range, including temperature compensation.

25.10.1.5 4-20mA output only. Voltage output is not acceptable.

25.11 CO_2 Sensors

25.11.1 Provide CO_2 sensors for either wall or duct mounting applications as specified. Provide a heavy duty metal guard to protect the sensor when mounted on walls. Provide the factory-supplied duct mounting kit for all duct mount applications.

25.11.2 The sensor shall be microprocessor controlled, fully digital, non-dispersive dual wavelength infrared technology with temperature compensation. The device output shall be 4 to 20mA.

25.11.3 The sensor shall have a measurement range of 0 to 3000ppm with an accuracy of +/- 25ppm in the 15-30C range. Long term stability shall be no greater than 20 ppm per year. The user selectable range shall be 0 to 1500ppm.

25.11.4 Install the sensor in accordance with all manufacturer's instructions. Wall mounted sensors shall be installed at a minimum height of 72" above the finished floor. Sensors shall not be mounted on an outside wall, close to a window, door or in draft areas with direct airflow.

25.12 Lighting Relays

25.12.1 All relays used for switching lighting loads shall be the latching type. Maintained relays or contactors shall not be accepted.

25.12.2 Provide custom lighting enclosures to house all lighting relays. The enclosures shall be equipped with barriers to separate the control and load wiring.

25.12.3 Provide local ON and OFF pushbuttons at each lighting relay enclosure to allow for manual operation of all lighting relays in the case of BAS panel failure. If a lighting panel is located in an area accessible by non-maintenance authorized staff, provide momentary key switches in lieu of pushbuttons. The key type shall be designated by Go Transit/Metrolinx. Deliver all keys to the Go Transit/Metrolinx representative at the completion of the project.

25.13 **Flow Switches**.

25.13.1 Flow-proving switches shall be paddle (water service only) or differential pressure type (air or water service). Switches shall be UL listed, SPDT snap-acting, and pilot duty rated (125 VA minimum).

25.13.2 Paddle switches shall have adjustable sensitivity and NEMA 1 enclosure unless otherwise specified.

25.13.3 Differential pressure switches shall have scale range and differential suitable for intended application and NEMA 1 enclosure unless otherwise specified.

25.14 **Relays**

25.14.1 Control Relays. Control relays shall be plug-in type, ULC listed, and shall have dust cover and LED “energized” indicator. Contact rating, configuration, and coil voltage shall be suitable for application.

25.14.2 Time Delay Relays. Time delay relays shall be solid-state plug-in type, UL listed, and shall have adjustable time delay. Delay shall be adjustable ±100% from setpoint shown. Contact rating, configuration, and coil voltage shall be suitable for application. Provide NEMA 1 enclosure for relays not installed in local control panel.

25.15 **Override Timers**

25.15.1 Unless implemented in control software, override timers shall be spring-wound line voltage, UL Listed, with contact rating and configuration required by application. Provide 0–6 hour calibrated dial unless otherwise specified. Flush mount timer on local control panel face or where shown.

25.16 **Current Transmitters**

25.16.1 AC current transmitters shall be self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4–20 mA two-wire output. Full-scale unit ranges shall be 10 A, 20 A, 50 A, 100 A, 150 A, and 200 A,

with internal zero and span adjustment. Unit accuracy shall be ±1% full-scale at 500 ohm maximum burden.

25.16.2 Transmitter shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA recognized.

25.16.3 Unit shall be split-core type for clamp-on installation on existing wiring.

25.17 **Current Transformers**

25.17.1 AC current transformers shall be UL/CSA recognized and shall be completely encased (except for terminals) in approved plastic material.

25.17.2 Transformers shall be available in various current ratios and shall be selected for ±0.2% accuracy at 5 A full-scale output.

25.17.3 Use fixed-core transformers for new wiring installation and split-core transformers for existing wiring installation.

25.18 **Voltage Transmitters**

25.18.1 AC voltage transmitters shall be self-powered single-loop (two-wire) type, 4–20 mA output with zero and span adjustment.

25.18.2 Adjustable full-scale unit ranges shall be 100–130 Vac, 200–250 Vac, 250–330 Vac, and 400–600 Vac. Unit accuracy shall be ±1% full-scale at 500 ohm maximum burden.

25.18.3 Transmitters shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA recognized at 600 Vac rating.

25.19 **Voltage Transformers**

25.19.1 AC voltage transformers shall be UL/CSA recognized, 600 Vac rated, and shall have built-in fuse protection.

25.19.2 Transformers shall be suitable for ambient temperatures of 4°C–55°C (40°F–130°F) and shall provide ±0.5% accuracy at 24 Vac and 5 VA load.

25.19.3 Windings (except for terminals) shall be completely enclosed with metal or plastic.

25.20 **Power Monitors**

25.20.1 Selectable rate pulse output for kWh reading, 4–20 mA output for kW reading, N.O. alarm contact, and ability to operate with 5.0 amp current inputs or 0–0.33 volt inputs.

25.20.2 1.0% full-scale true RMS power accuracy, +0.5 Hz, voltage input range 120–600 V, and auto range select.

25.20.3 Under voltage/phase monitor circuitry.

25.20.4 NEMA 2 enclosure.

25.20.5 Current transformers having a 0.5% FS accuracy, 600 VAC isolation voltage with 0–0.33 V output. If 0–5 A current transformers are provided, a three-phase disconnect/shorting switch assembly is required.

25.21 Hydronic Flowmeters

25.21.1 Insertion-Type Turbine Meter

25.21.1.1 Dual counter-rotating axial turbine elements, each with its own rotational sensing system, and an averaging circuit to reduce measurement errors due to swirl and flow profile distortion. Single turbine for piping 2 inches and smaller. Flow sensing turbine rotors shall be non-metallic and not impaired by magnetic drag.

25.21.1.2 Insertion type complete with ‘hot-tap’ isolation valves to enable sensor removal without water supply system shutdown.

25.21.1.3 Sensing method shall be impedance sensing (non magnetic and non photoelectric)

25.21.1.4 Volumetric accuracy

- ± 0.5% of reading at calibrated velocity
- ± 1% of reading from 3 to 30 ft/s (10:1 range)
- ± 2% of reading from 0.4 to 20 ft/s (50:1 range)

25.21.1.5 Each sensor shall be individually calibrated and tagged accordingly against the manufacturer’s primary standards which must be accurate to within 0.1% of flow rate and traceable to the National Institute of Standards and Technology (NIST).

25.21.1.6 Maximum operating pressure of 400 psi and maximum operating temperature of 200°F continuous (220°F peak).

25.21.1.7 All wetted metal parts shall be constructed of 316 stainless steel.

25.21.1.8 Analog outputs shall consist of non interactive zero and span adjustments, a DC linearly of 0.1% of span, voltage output of 0-10 Vdc, and current output of 4-20 mA.

25.21.2 Magnetic Flow-Tube Type Flowmeter

25.21.2.1 Sensor shall be a magnetic flowmeter, which utilizes Faraday's Law to measure volumetric fluid flow through a pipe. The flowmeter shall consist of two elements, the sensor and the electronics. The sensor shall generate a measuring signal proportional to the flow velocity in the pipe. The electronics shall convert this EMF into a standard current output.

25.21.2.2 Electronic replacement shall not affect meter accuracy (electronic units are not matched with specific sensors).

25.21.2.3 Four-wire, externally powered, magnetic type flow transmitter with adjustable span and zero, integrally mounted to flow tube. Output signal shall be a digital pulse proportional to the flow rate (to provide maximum accuracy and to handle abrupt changes in flow). Standard 4-20 mA or 0-10 Vdc outputs may be used provided accuracy is as specified.

25.21.2.4 Flow Tube:

- ANSI class 150 psig steel
- ANSI flanges
- Protected with PTFE, PFA, or ETFE liner rated for 245°F minimum fluid temperature

25.21.2.5 Electrode and grounding material

- 316L Stainless steel or Hastelloy C
- Electrodes shall be fused to ceramic liner and not require o-rings.
- Electrical Enclosure: NEMA 4, 7

25.21.2.6 Approvals:

- ULC or CSA
- NSF Drinking Water approval for domestic water applications

25.21.2.7 Performance

- Accuracy shall be ±0.5% of actual reading from 3 to 30 ft/s flow velocities, and 0.015 ft/s from 0.04 to 3 ft/s.
- Stability: 0.1% of rate over six months.
- Meter repeatability shall be ±0.1% of rate at velocities > 3 ft/s.

25.21.3 Magnetic Insertion-Type Flowmeter

25.21.3.1 Magnetic Faraday point velocity measuring device.

25.21.3.2 Insertion type complete with hot-tap isolation valves to enable sensor removal without water supply system shutdown.

25.21.3.3 4-20 mA transmitter proportional to flow or velocity.

25.21.3.4 Accuracy: larger of 1% of reading and 0.2 ft/s.

25.21.3.5 Flow range: 0.2 to 20 ft/s, bidirectional.

25.21.3.6 Each sensor shall be individually calibrated and tagged accordingly against the manufacturer's primary standards which must be accurate to within 0.1% of flow rate and traceable to the National Institute of Standards and Technology (NIST).

25.21.4 Vortex Shedding Flowmeter

25.21.4.1 Output: 4-20 mA, 0-10 Vdc, 0-5 Vdc.
25.21.4.2 Maximum Fluid Temperature: 800ºF (427 °C).
25.21.4.3 Wetted Parts: Stainless Steel.
25.21.4.4 Housing: NEMA 4X.
25.21.4.5 Turndown: 25:1 minimum.
25.21.4.6 Accuracy: 0.5% of calibrated span for liquids, 1% of calibrated span for steam and gases.
25.21.4.7 Body: Wafer style or ANSI flanged to match piping specification.

25.21.5 Transit-Time Ultrasonic Flowmeter

25.21.5.1 Clamp-On transit-time ultrasonic flowmeter
25.21.5.2 Wide-Beam transducer technology
25.21.5.3 4-20 mA transmitter proportional to flow or velocity.
25.21.5.4 Accuracy: 0.5% of reading in range 1 to 30 ft/s, 0.001 ft/s sensitivity.

25.22 **Thermal Energy Meters**

25.22.1 Matched RTD, solid state, or thermistor temperature sensors with a differential temperature accuracy of ±0.15°F.

25.22.2 Flow meter : See "Hydronic Flowmeters" section.

25.22.3 Unit accuracy of ±1% factory calibrated, traceable to NIST with certification.

25.22.4 NEMA 1 enclosure.

25.22.5 Panel mounted display.

25.22.6 ULC listed.

25.22.7 Isolated 4–20 ma signals for energy rate and supply and return temperatures and flow

25.23 Current Switches

25.23.1 Current-operated switches shall be self-powered, solid-state with adjustable trip current. Select switches to match application current and DDC system output requirements.

25.24 Pressure Transducers

25.24.1 Transducers shall have linear output signal and field-adjustable zero and span.

25.24.2 Transducer sensing elements shall withstand continuous operating conditions of positive or negative pressure 50% greater than calibrated span without damage.

25.24.3 Water pressure transducer diaphragm shall be stainless steel with minimum proof pressure of 1000 kPa (150 psi). Transducer shall have 4–20 mA output, suitable mounting provisions, and block and bleed valves.

25.24.4 Water differential pressure transducer diaphragm shall be stainless steel with minimum proof pressure of 1000 kPa (150 psi). Over-range limit (differential pressure) and maximum static pressure shall be 2000 kPa (300 psi.)Transducer shall have 4–20 mA output, suitable mounting provisions, and 5-valve manifold.

25.24.5 Differential Pressure Switches. Differential pressure switches (air or water service) shall be UL listed, SPDT snap-acting, pilot duty rated (125 VA minimum) and shall have scale

range and differential suitable for intended application and NEMA 1 enclosure unless otherwise specified.

25.25 **Pressure-Electric (PE) Switches**

25.25.1 Shall be metal or neoprene diaphragm actuated, operating pressure rated for 0–175 kPa (0–25 psig), with calibrated scale minimum setpoint range of 14–125 kPa (2–18 psig) minimum, ULC listed.

25.25.2 Provide one- or two-stage switch action (SPDT, DPST, or DPDT) as required by application electrically rated for pilot duty service (125 VA minimum) and/or for motor control.

25.25.3 Switches shall be open type (panel-mounted) or enclosed type for remote installation. Enclosed type shall be NEMA 2 unless otherwise specified.

25.25.4 Each pneumatic signal line to PE switches shall have permanent indicating gauge.

25.26 **Occupancy Sensors**.

25.26.1 Occupancy sensors shall utilize Passive Infrared (PIR) and/or Microphonic Passive technology to detect the presence of people within a room. Sensors shall be mounted as indicated on the approved drawings. The sensor output shall be accessible by any lighting and/or HVAC controller in the system. Occupancy sensors shall be capable of being powered from the lighting or HVAC control panel, as shown on the drawings. Occupancy sensor delay shall be software adjustable through the user interface and shall not require manual adjustment at the sensor.

25.27 **Oil Interceptors**

25.27.1 Large Capacity all type 304 stainless steel fabrication with heavy duty traffic cover rated at 10,000 lbs (4,536 kg) load.

25.27.2 Fiberglass sensor box containing an electronic oil lever sensor (specify right or left side), a fiberglass display box with one green power light, red oil level light, audible alarm and junction box.

25.27.3 Complete with bronze cleanout plug and visible double wall trap seal, removable combination pressure equalizing/flow diffusing baffle and sediment bucket, horizontal baffle, and vent connections either side. Secured gasketed non-skid cover with integral flow control fitting.

25.27.4 Connect local controller supplied with equipment to BAS, duplicating the monitored parameters (power on, oil level and alarm).

25.28 **Local Control Panels**

25.28.1 All indoor control cabinets shall be fully enclosed NEMA 1 construction with (hinged door) key-lock latch and removable subpanels. A single key shall be common to all field panels and subpanels.

25.28.2 Interconnections between internal and face-mounted devices shall be prewired with color-coded stranded conductors neatly installed in plastic troughs and/or tie-wrapped. Terminals for field connections shall be UL listed for 600 volt service, individually identified per control/ interlock drawings, with adequate clearance for field wiring. Control terminations for field connection shall be individually identified per control drawings.

25.28.3 Provide ON/OFF power switch with over current protection for control power sources to each local panel.

25.29 **Push Buttons**

25.29.1 Where specified, provide a push button with the following minimum characteristics:

25.29.1.1 The push button shall be surface mounted.
25.29.1.2 The unit shall have a button that is flush with casing.
25.29.1.3 The casing shall be heavy-duty and abrasion-proof.

26. WIRING

26.1 Provide copper wiring, plenum cable. Insulated wire shall use copper conductors and shall be ULC listed for 90°C (200°F) minimum service.

27. FIBER OPTIC CABLE SYSTEM

27.1 **Optical Cable**

27.1.1 Optical cables shall be duplex 900 mm tight-buffer construction designed for intra-building environments. Sheath shall be UL listed OFNP in accordance with NEC Article 770. Optical fiber shall meet the requirements of FDDI, ANSI X3T9.5 PMD for 62.5/125mm.

27.1.2 Connectors. Field terminate optical fibers with ST type connectors. Connectors shall have ceramic ferrules and metal bayonet latching bodies.

28. INSTALLATION AND VERIFICATION

28.1 Coordination

28.1.1 Where the mechanical work will be installed in close proximity to, or will interfere with, work of other trades, space conditions shall be worked out such as to make a satisfactory adjustment.

28.2 General Workmanship

28.2.1 Install equipment, piping, and wiring/raceway parallel to building lines (i.e. horizontal, vertical, and parallel to walls) wherever possible.

28.2.2 Provide sufficient slack and flexible connections to allow for vibration of piping and equipment. Install equipment in readily accessible locations as defined by OESC (Ontario Electrical Safety Code)

28.2.3 Verify integrity of all wiring to ensure continuity and freedom from shorts and grounds.

28.2.4 All equipment, installation, and wiring shall comply with industry specifications and standards for performance, reliability, and compatibility and be executed in strict adherence to local codes and standard practices.

28.3 Field Quality Control

28.3.1 All work, materials, and equipment shall comply with rules and regulations of applicable local, provincial, and federal codes and ordinances.

28.4 Wiring

28.4.1 All control and interlock wiring shall comply with provincial, federal and local electrical codes.

28.4.2 Also refer to the communication requirements specified elsewhere in this document.

28.4.3 All wiring in mechanical, electrical, or service rooms – or where subject to mechanical damage – shall be installed in raceway at levels below 3 m (10ft). Class 2 wiring shall not be installed in raceways containing Class 1 wiring. Boxes and panels containing high-voltage wiring and equipment may not be used for low-voltage wiring except for the purpose of interfacing the two (e.g. relays and transformers). Do not install wiring in raceway containing tubing. Where Class 2 wiring is run exposed, wiring is to be run parallel along a surface or perpendicular to it and neatly tied at 3 m (10 ft) intervals.

28.4.4 Where plenum cables are used without raceway, they shall be supported from or anchored to structural members. Cables shall not be supported by or anchored to ductwork, electrical raceways, piping, or ceiling suspension systems. All wire-to-device connections shall be made at a terminal block or terminal strip. All wire-to-wire connections shall be at a terminal block. All wiring within enclosures shall be neatly bundled and anchored to permit access and prevent restriction to devices and terminals.

28.4.5 Maximum allowable voltage for control wiring shall be 120 V. If only higher voltages are available, the contractor shall provide step-down transformers. All wiring shall be installed as continuous lengths, with no splices permitted between termination points.

28.4.6 Plenum wiring shall be installed in sleeves where it passes through walls and floors. Maintain fire rating at all penetrations. Size of raceway and size and type of wire type shall be the responsibility of the contractor in keeping with the manufacturer's recommendations and OESC requirements, except as noted elsewhere. Include one pull string in each raceway 2.5 cm (1 in.) or larger.

28.4.7 Use color-coded conductors throughout with conductors of different colors. Control and status relays are to be located in designated enclosures only. These enclosures include packaged equipment control panel enclosures unless they also contain Class 1 starters.

28.4.8 Conceal all raceways except within mechanical, electrical, or service rooms. Install raceway to maintain a minimum clearance of 15 cm (6 in.) from high-temperature equipment (e.g. steam pipes or flues). Secure raceways with raceway clamps fastened to the structure and spaced according to code requirements. Raceways and pull boxes may not be hung on flexible duct strap or tie rods. Raceways may not be run on or attached to ductwork.

28.4.9 Adhere to this specification's Division 26 requirements where raceway crosses building expansion joints. Install insulated bushings on all raceway ends and openings to enclosures. Seal top end of vertical raceways. All control and/or interlock wiring shall be terminated and updated (as-built) wiring diagrams with terminations identified at the job site shall be maintained. Flexible metal raceways and liquid-tight flexible metal raceways shall not exceed 1 m (3 ft) in length and shall be supported at each end. Flexible metal raceway less than ½ in. electrical trade size shall not be used. In areas exposed to moisture, including chiller and boiler rooms, liquid-tight, flexible metal raceways shall be used. Raceway must be rigidly installed, adequately supported, properly reamed at both ends, and left clean and free of obstructions. Raceway sections shall be joined with couplings (according to code). Terminations must be made with fittings at boxes, and ends not terminating in boxes shall have bushings installed.

28.5 Communication Wiring

28.5.1 All cabling shall be installed in a neat and workmanlike manner. Follow manufacturer's installation recommendations for all communication cabling. Do not install communication wiring in raceways and enclosures containing Class 1 or other Class 2 wiring.

28.5.2 Maximum pulling, tension, and bend radius for the cable installation, as specified by the cable manufacturer, shall not be exceeded during installation. The integrity of the entire network shall be tested following cable installation. Use appropriate test measures for each particular cable.

28.5.3 When a cable enters or exits a building, a lightning arrestor must be installed between the lines and ground. The lighting arrestor shall be installed according to manufacturer's instructions. All runs of communication wiring shall be unspliced length when that length is commercially available.

28.5.4 All communication wiring shall be labeled to indicate origination and destination data. All communication wiring shall be labeled to indicate origination and destination data.

28.5.5 Grounding of coaxial cable shall be in accordance with NEC regulations article on "Communications Circuits, Cable, and Protector Grounding."

28.5.6 BACnet MS/TP communications wiring shall be installed in accordance with ASHRAE/ANSI Standard 135. This includes but is not limited to:

- The network shall use shielded, twisted-pair cable with characteristic impedance between 100 and 120 ohms. Distributed capacitance between conductors shall be less than 100 pF per meter (30 pF per foot.)
- The maximum length of an MS/TP segment is 1200 meters (4000 ft) with AWG 18 cable. The use of greater distances and/or different wire gauges shall comply with the electrical specifications of EIA-485.
- The maximum number of nodes per segment shall be 32, as specified in the EIA 485 standard. Additional nodes may be accommodated by the use of repeaters.
- An MS/TP EIA-485 network shall have no T connections.

28.6 **Fiber Optic Cable**

28.6.1 Maximum pulling tensions as specified by the cable manufacturer shall not be exceeded during installation. Post-installation residual cable tension shall be within cable manufacturer's specifications.

28.6.2 All cabling and associated components shall be installed in accordance with manufacturers' instructions. Minimum cable and unjacketed fiber bend radii, as specified by cable manufacturer, shall be maintained.

28.7 **Installation of Sensors**

28.7.1 Install sensors in accordance with the manufacturer's recommendations.

28.7.2 Mount sensors rigidly and adequately for environment within which the sensor operates.

28.7.3 Room temperature sensors shall be installed on concealed junction boxes properly supported by wall framing.

28.7.4 All wires attached to sensors shall be sealed in their raceways or in the wall to stop air transmitted from other areas from affecting sensor readings.

28.7.5 Low-limit sensors used in mixing plenums shall be installed in a serpentine manner horizontally across duct. Each bend shall be supported with a capillary clip. Provide 3 m (1 ft) of sensing element for each 1 m^2(1 ft^2) of coil area.

28.7.6 All pipe-mounted temperature sensors shall be installed in wells. Install liquid temperature sensors with heat-conducting fluid in thermal wells.

28.7.7 Install outdoor air temperature sensors on north wall, complete with sun shield at designated location.

28.7.8 Install snow/moisture/slab sensors in a location where it will not be affected by abnormal temperature conditions that may occur near buildings, hot air exhaust ducts or other heat sources, or sunny areas within a larger slab area. Do not to place the sensor where standing water could accumulate on its surface. Do not place the sensor in areas where drainage is considerably better than the surrounding area. The snow / ice sensor shall not be installed in locations where vehicles park, near building overhangs or near trees since this may interfere with snow fall accumulation. The top of the snow/ice sensor should be flush and parallel to that of the snow melt surface. When the sensor is installed on a sloped driveway, the sensor must be installed near the lowest elevation of the slope.

28.8 **Actuators**

28.8.1 Mount and link control damper actuators according to manufacturer's instructions.

28.8.2 To compress seals when spring-return actuators are used on normally closed dampers, power actuator to approximately 5° open position, manually close the damper, and then tighten the linkage.

28.8.3 Check operation of damper/actuator combination to confirm that actuator modulates damper smoothly throughout stroke to both open and closed positions.

28.8.4 Provide all mounting hardware and linkages for actuator installation.

28.9 **Warning Labels**

28.9.1 Permanent warning labels shall be affixed to all equipment that can be automatically started by the control system.

28.9.2 Labels shall use white lettering (12-point type or larger) on a red background.

28.9.3 Warning labels shall read as follows:

C A U T I O N
This equipment is operating under automatic control and may start or stop at any time without warning. Switch disconnect to"Off" position before servicing.

28.9.4 Permanent warning labels shall be affixed to all motor starters and control panels that are connected to multiple power sources utilizing separate disconnects.

28.9.5 Labels shall use white lettering (12-point type or larger) on a red background.

28.9.6 Warning labels shall read as follows:

C A U T I O N
This equipment is fed from more than one power source with separate disconnects. Disconnect all power sources before servicing.

28.10 **Identification of Hardware and Wiring**

28.10.1 All wiring and cabling, including that within factory-fabricated panels shall be labeled at each end within 5 cm (2 in.) of termination with control system address or termination number.

28.10.2 All pneumatic tubing shall be labeled at each end within 5 cm (2 in.) of termination with a descriptive identifier.

28.10.3 Permanently label or code each point of field terminal strips to show the instrument or item served.

28.10.4 Identify control panels with minimum 1 cm (½ in.) letters on laminated plastic nameplates.

28.10.5 Identify all other control components with permanent labels. All plug-in components shall be labeled such that label removal of the component does not remove the label.

28.10.6 Identify room sensors related to terminal boxes or valves with nameplates.

28.10.7 Manufacturers' nameplates and ULC or CSA labels shall be visible and legible after equipment is installed.

28.10.8 Identifiers shall match record documents.

28.11 **Controllers**

28.11.1 Provide a separate controller for each HVAC system. A DDC controller may control more than one system provided that all points associated with the system are assigned to the same DDC controller. Points used for control loop reset, such as outside air or space temperature, are exempt from this requirement.

28.11.2 Building Controllers and Custom Application Controllers shall be selected to provide the required I/O point capacity required to monitor all of the hardware points listed in the design documentation.

28.11.3 Unless instructed otherwise by Go/Metrolinx representatives, the BAS controllers, local BAS workstation shall be installed in the Electrical Room and/or the Telecommunication Room.

28.12 **Programming**

28.12.1 Provide sufficient internal memory for the specified sequences of operation and trend logging.

28.12.2 Point Naming. Name points as shown on the equipment points list provided with each sequence of operation. Where multiple points with the same name reside in the same controller, each point name may be customized with its associated Program Object number. For example, "Zone Temp 1" for Zone 1, "Zone Temp 2" for Zone 2.

28.13 **Software Programming.**

28.13.1 Provide programming for the system and adhere to the sequences of operation provided. All other system programming necessary for the operation of the system, but not specified in this document, also shall be provided by the contractor. Embed into the control program sufficient comment statements to clearly describe each section of the program. The comment statements shall reflect the language used in the sequences of operation. Use the appropriate technique based on the following programming types:

28.13.1.1 Text-based:

- Must provide actions for all possible situations
- Must be modular and structured
- Must be commented

28.13.1.2 Graphic-based:

- Must provide actions for all possible situations
- Must be documented

28.13.1.3 Parameter-based:

- Must provide actions for all possible situations
- Must be documented.
- Operator Interface.

28.14 **Standard Graphics**

28.14.1 Provide graphics for all mechanical systems and floor plans of the building. Point information on the graphic displays shall dynamically update. Show on each graphic all input and output points for the system. Also show relevant calculated points such as setpoints. As a minimum, show on each equipment graphic the input and output points and relevant calculated.

28.14.2 Provide all the labor necessary to install, initialize, start up, and troubleshoot all operator interface software and its functions as described in this section. This includes any operating system software, the operator interface database, and any third-party software installation and integration required for successful operation of the operator interface.

28.15 **Control System Checkout and Testing**

28.15.1 Startup Testing.

28.15.1.1 All testing listed in this article shall be performed by the contractor and shall make up part of the necessary verification of an operating control system. This testing shall be completed before the owner's representative is notified of the system demonstration.

28.15.1.2 Provide all labor and test apparatus required to calibrate and prepare for service of all instruments, controls, and accessory equipment furnished under this specification.

28.15.1.3 Verify that all control wiring is properly connected and free of all shorts and ground faults. Verify that terminations are tight.

28.15.1.4 Enable the control systems and verify calibration of all input devices individually. Perform calibration procedures according to manufacturers' recommendations.

28.15.1.5 Verify that all digital output devices (relays, solenoid valves, two-position actuators and control valves, magnetic starters, etc.) operate properly and that the normal positions are correct.

28.15.1.6 Verify that all analog output devices (I/Ps, actuators, etc.) are functional, that start and span are correct, and that direction and normal positions are correct. The contractor shall check all control valves and automatic dampers to ensure proper action and closure. The contractor shall make any necessary adjustments to valve stem and damper blade travel.

28.15.1.7 Verify that the system operation adheres to the sequences of operation. Simulate and observe all modes of operation by overriding and varying inputs and schedules. Tune all DDC loops.

28.15.2 Alarms and Interlocks:

28.15.2.1 Check each alarm separately by including an appropriate signal at a value that will trip the alarm.

28.15.2.2 Interlocks shall be tripped using field contacts to check the logic, as well as to ensure that the fail-safe condition for all actuators is in the proper direction.

28.15.2.3 Interlock actions shall be tested by simulating alarm conditions to check the initiating value of the variable and interlock action

28.16 **Control System Demonstration**

28.16.1 Demonstration.

28.16.1.1 Prior to acceptance, the control system shall undergo a series of performance tests to verify operation and compliance with this specification. These tests shall occur after the Contractor has completed the installation, started up the system, and performed his/her own tests.

28.16.1.2 This contractor shall be responsible for the “end to end” commissioning, testing, verification and start-up of the complete control system hardware including panels, sensors, transducers, end devices, relays and wiring. Where applicable, this shall include any points from an existing and/or re-used automation system in the building.

28.16.1.3 The tests described in this section are to be performed in addition to the tests that are performed as a necessary part of the installation, start-up, and debugging process. The consultant will be present to observe and review these tests. The engineer shall be notified at least 10 days in advance of the start of the testing procedures.

28.16.1.4 The contractor shall provide at least two persons equipped with two-way communication and shall demonstrate actual field operation of each control and sensing point for all modes of operation including day, night, occupied, unoccupied, fire/smoke alarm, seasonal changeover, and power failure modes. The purpose is to demonstrate the calibration, response, and action of every point and system. Any test equipment required to prove the proper operation shall be provided by and operated by the contractor.

28.16.1.5 As each control input and output is checked, a log shall be completed showing the date, technician’s initials, and any corrective action taken or needed.

28.17 **Verification and Hardware Commissioning**

28.17.1 Analogue inputs (i.e. temperatures, pressure, etc.) shall be verified with an approved calibration device. All actual temperature readings should be with +/- 1C of the readings observed at the workstation. Record calibration adjustments and settings.

28.17.2 Analogue outputs shall be verified by manually commanding the output channel from the operator workstation to two or more positions within the 0-100% range and verifying the actual position of the actuator or device. All devices shall operate over their entire 0-100% range from a minimum control range of 10-90%. Record the actual output scale range (channel output voltage versus controller command) for each analogue end device

28.17.3 Digital outputs shall be verified by witnessing the actual start/stop operation of the equipment under control.

28.17.4 Digital inputs shall be verified by witnessing the status of the input point as the equipment is manually cycled on and off.

28.17.5 Record all out-of-season or unverified points in the commissioning report as "non-commissioned". Commissioning of out of season items should be scheduled during the appropriate season. Unverified points will be accepted as "non-commissioned" at Metrolinx's discretion.

28.17.6 The BAS field panel power source shall be toggled on and off to ensure reboot functionality and power down memory retention of all parameters. During the power down test, all controlled system outputs shall go to their fail-safe position.

28.17.7 Verify PID loop tuning parameters by applying a step change to the current setpoint and observing the response of the controlled device. Setpoint should be reached in an acceptable period of time without excessive cycling or hunting of the controlled device.

28.17.8 Provide a graph of the trend response to setpoint change for important controlled devices (e.g. valves 1-inch or larger, dampers on major air handlers, etc.)

28.17.9 Provide confirmation that a series of test alarms has been successfully received at a designated remote monitoring workstations.

28.17.10 Include with the hardware commissioning report a site floor plan indicating the location of all equipment installed in concealed or recessed locations (e.g. interposing relays in ceiling spaces).

28.17.11 Provide testing of all LAN cabling to ensure that 100Mb bandwidth is supported.

28.17.12 Verify conformance with TIA /EIA TSB-67 - Basic Link Test using a Level 2, bi-directional tester. Provide all equipment necessary to carry out the required tests.

28.17.13 The hardware commissioning report must be signed and dated by the Contractor's technician performing the tests and participating Consultant.

28.17.14 At the completion of site commissioning, submit four (4) copies of hardware commissioning report to the Owner.

28.18 **System Performance.**

28.18.1 Demonstrate compliance with sequences of operation through all modes of operation.

28.18.2 Demonstrate complete operation of operator interface.

28.18.3 Additionally, the following items shall be demonstrated:

28.18.3.1 DDC loop response. The contractor shall supply trend data output in a graphical form showing the step response of each DDC loop. The test shall show the loop's response to a change in set point, which represents a change of actuator position of at least 25% of its full range. The sampling rate of the trend shall be from 10 seconds to 3 minutes, depending on the speed of the loop. The trend

data shall show for each sample the set point, actuator position, and controlled variable values. Any loop that yields unreasonably under-damped or over-damped control shall require further tuning by the Contractor.

28.18.3.2 Demand limiting. The contractor shall supply a trend data output showing the action of the demand limiting algorithm. The data shall document the action on a minute-by-minute basis over at least a 30-minute period. Included in the trend shall be building kW, demand limiting set point, and the status of sheddable equipment outputs.

28.18.3.3 Optimum start/stop. The contractor shall supply a trend data output showing the capability of the algorithm. The change-of-value or change-of-state trends shall include the output status of all optimally started and stopped equipment, as well as temperature sensor inputs of affected areas.

28.18.3.4 Interface to the building fire alarm system.

28.18.3.5 Operational logs for each system that indicate all set points, operating points, valve positions, mode, and equipment status shall be submitted to the architect/engineer. These logs shall cover three 48-hour periods and have a sample frequency of not more than 10 minutes. The logs shall be provided in both printed and disk formats.

28.18.4 Any tests that fail to demonstrate the operation of the system shall be repeated at a later date. The contractor shall be responsible for any necessary repairs or revisions to the hardware or software to successfully complete all tests.

28.19 **Acceptance.**

28.19.1 At the completion of the site hardware inspection, the Contractor shall test and verify that the system programming, graphics and alarm software is operating correctly and is in compliance all requirements of the specifications.

28.19.2 The Contractor shall provide written notification to the Go Transit/Metrolinx representative and the Consultant that the site is ready for the Substantial Completion Inspection by the Consultant.

28.19.3 At the request of the Consultant, the contractor shall arrange for qualified BAS installer staff to be present during the Substantial Completion Inspection and any subsequent inspections that may be scheduled.

28.19.4 The Substantial Completion Inspection should not yield anything more than a small number of minor deficiencies related to the project work. It is the responsibility of the contractor to thoroughly review the project work to ensure that this is the case prior to requesting a Substantial Completion Inspection.

28.19.5 At the conclusion of the Substantial Completion Inspection, the Consultant shall issue a comprehensive site deficiency report to the Contractor for his immediate action.

28.19.6 The Contractor shall correct all items noted in the site deficiency report within ten (10) business days of receiving the inspection report.

28.19.7 The Contractor shall provide written notification to the Go Transit/Metrolinx representative that all items on the Consultant's site deficiency report have been corrected.

28.20 **Cleaning**

28.20.1 All debris resulting from the controls installation activities shall be cleaned daily. Remove all cartons, containers, crates, etc., under his/her control as soon as their contents have been removed. Waste shall be collected and placed in a designated location.

28.20.2 At the completion of work, all equipment shall be checked for paint damage, and any factory-finished paint that has been damaged shall be repaired to match the adjacent areas. Any cabinet or enclosure that has been deformed shall be replaced with new material and repainted to match the adjacent areas.

28.21 **Training**

28.21.1 Provide training for a designated staff of Owner's representatives. Training shall be provided via self-paced training, web-based or computer-based training, classroom training, or a combination of training methods.

28.21.2 Training shall enable students to accomplish the following objectives.

28.21.3 Day-to-day Operators:

- Proficiently operate the system
- Understand control system architecture and configuration
- Understand DDC system components
- Understand system operation, including DDC system control and optimizing routines (algorithms)
- Operate the workstation and peripherals
- Log on and off the system
- Access graphics, point reports, and logs
- Adjust and change system set points, time schedules, and holiday schedules
- Recognize malfunctions of the system by observation of the printed copy and graphical visual signals
- Understand system drawings and Operation and Maintenance manual
- Understand the job layout and location of control components
- Access data from DDC controllers and ASCs

- Operate portable operator's terminals

28.21.4 Advanced Operators:

- Make and change graphics on the workstation
- Create, delete, and modify alarms, including annunciation and routing of these
- Create, delete, and modify point trend logs and graph or print these both on an ad-hoc basis and at user-definable time intervals
- Create, delete, and modify reports
- Add, remove, and modify system's physical points
- Create, modify, and delete programming
- Add panels when required
- Add operator interface stations
- Create, delete, and modify system displays, both graphical and others
- Perform DDC system field checkout procedures
- Perform DDC controller unit operation and maintenance procedures
- Perform workstation and peripheral operation and maintenance procedures
- Perform DDC system diagnostic procedures
- Configure hardware including PC boards, switches, communication, and I/O points
- Maintain, calibrate, troubleshoot, diagnose, and repair hardware
- Adjust, calibrate, and replace system components

28.21.5 System Managers/Administrators:

- Maintain software and prepare backups
- Interface with job-specific, third-party operator software
- Add new users and understand password security procedures

28.21.6 Organize the training into sessions or modules for the three levels of operators listed above. (Day-to-Day Operators, Advanced Operators, System Managers and Administrators). Students will receive one or more of the training packages, depending on knowledge level required.

28.21.7 Provide course outline and materials according to the "Submittals" article in Part 1 of this specification. Provide one copy of training material per student.

28.21.8 The instructor(s) shall be factory-trained and experienced in presenting this material.

28.21.9 Classroom training shall be done using a network of working controllers representative of installed hardware.

28.22 Controls Communication Protocol

28.22.1 General.

28.22.1.1 The electronic controls packaged with this equipment shall communicate with the building direct digital control (DDC) system. The DDC system shall communicate with these controls to read the information and change the control setpoints as shown in the points list, sequences of operation, and control schematics. The information to be communicated between the DDC system and these controls shall be in the standard object format as defined in ANSI/ASHRAE Standard 135 (BACnet). Controllers shall communicate with other BACnet objects on the internetwork using the Read (Execute) Property service as defined in Clause 15.5 of Standard 135.

28.22.2 Distributed Processing.

28.22.2.1 The controller shall be capable of stand-alone operation and shall continue to provide control functions if the network connection is lost.

28.22.3 I/O Capacity.

28.22.3.1 The controller shall contain sufficient I/ O capacity to control the target system.

28.22.3.2 The Controller shall have a physical connection for a laptop computer or a portable operator's tool.

28.22.4 Environment.

28.22.4.1 The hardware shall be suitable for the anticipated ambient conditions.

28.22.4.2 Controllers used outdoors and/or in wet ambient conditions shall be mounted within waterproof enclosures and shall be rated for operation at between minus -29°C to 60°C (-20°F to 140°F).

28.22.4.3 Controllers used in conditioned space shall be mounted in dust-proof enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

28.22.5 Serviceability.

28.22.5.1 Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to field removable, modular terminal strips or to a termination card connected by a ribbon cable.

28.22.6 Memory.

28.22.6.1 The Controller shall maintain all BIOS and programming information in the event of a power loss for at least 30 days.

28.22.7 Power.

28.22.7.1 Controller shall be able to operate at 90% to 110% of nominal voltage rating.

28.22.8 Transformer.

28.22.8.1 Power supply for the Controller must be rated at minimum of 125% of ASC power consumption and shall be fused or current limiting type.

28.23 **Start-Up and Checkout Procedures**

28.23.1 Start up, check out, and test all hardware and software and verify communication between all components.

28.23.2 Verify that all control wiring is properly connected and free of all shorts and ground faults. Verify that terminations are tight.

28.23.3 Verify that all analog and binary input/output points read properly.

28.23.4 Verify alarms and interlocks.

28.23.5 Verify operation of the integrated system.

29. SEQUENCES OF OPERATION

29.1 **General**

29.1.1 The sequences of operation described herein are to be used as generic guidelines only. Each project may have particular conditions that will require additional monitoring sensors and devices and more complex sequences of operation, depending on circumstances.

29.1.2 The consultant shall define in detail all aspects of the sequencing of operation for all equipment under all operational modes (summer, winter, occupied, unoccupied, alarm, etc), whether listed in this DRM document or not. A control diagram shall be prepared for each equipment, together with a tabular count of analogue/digital input and output points.

29.1.3 Multiple pieces of equipment of the same nature and operating in identical manner are allowed to be represented by a single schematic and tabular points count, provided that the number and designation of similar equipment is clearly indicated.

29.2 **Sanitary Exhaust Fans**

29.2.1 Sequencing

29.2.1.1 The exhaust fans shall be enabled/disabled based on an Owner-defined time of day schedule

29.2.2 Graphical representation

29.2.2.1 Exhaust fan, programmed status, actual status

29.2.3 Alarms

29.2.3.1 Discrepancy between fan programmed status and actual status

29.3 **Service Rooms Exhaust Fans**

29.3.1 Sequencing

29.3.1.1 The exhaust fans shall operate as required to maintain a space temperature setpoint. Where applicable, a motorized intake damper shall be hard-wired interlocked with the fan.

29.3.2 Graphical Representation

29.3.2.1 Exhaust fan, temperature setpoint, programmed fan status, actual space temperature, actual fan status.

29.3.3 Alarms

- Discrepancy between fan programmed status and actual status
- +/-5^{O}C difference between programmed and actual space temperature setpoint.

29.4 **General Purpose Exhaust Fans**

29.4.1 Sequencing

29.4.1.1 The exhaust fans shall be hard-wire interlocked with their associated air handling system

29.4.2 Graphical representation

29.4.2.1 Exhaust fan, programmed status, actual status

29.4.3 Alarms

- Discrepancy between fan programmed status and actual status

29.5 **Packaged Air Handling Units – Heating and Ventilation Only**

29.5.1 Sequencing

29.5.1.1 During occupied hours the supply fan shall operate continuously. The fresh air dampers shall open to the minimum position.

29.5.1.2 A space sensor shall allow the FAS to monitor the temperature in the areas served by the air handling unit. If the space temperature drops below the heating occupied setpoint, the heating section shall be enabled and shall modulate as required to maintain the setpoint.

29.5.1.3 The integral CO_2 sensor built into the air handling unit shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.5.1.4 During unoccupied periods and outdoor temperatures higher than 12^{O}C, the unit shall shut down. During unoccupied periods and outdoor temperatures lower than 12^{O}C, the unit shall operate only as necessary to maintain the heating unoccupied setpoint. During unoccupied hours, the fresh air damper shall remain fully closed and the fan shall operate only on a call for heat (Auto mode).

29.5.2 Graphical representation

29.5.2.1 Programmed space setpoint, actual space setpoint.

29.5.2.2 Air handling unit as a block, programmed/actual status of the fan, status of the heating section (status for each heating stage if multiple stages available), discharged air temperature, return air temperature, CO_2 ppm setpoint/actual value, position of O/A damper

29.5.3 Alarms

- discrepancy between fan programmed status and actual status
- failure of any heating stage to operate when called for
- +/-5^{O}C difference between programmed and actual space temperature setpoint.
- +/-5^{O}C difference between programmed and actual discharged air setpoint.
- +200 ppm CO_2 concentration higher than the setpoint

29.6 Packaged Air Handling Units – Heating and Ventilation Only + Auxiliary Heating

29.6.1 Sequencing

29.6.1.1 During occupied hours the supply fan shall operate continuously. The fresh air dampers shall open to the minimum position.

29.6.1.2 A duct sensor shall allow the FAS to monitor the discharged air temperature and modulate the heating section of the unit to maintain the setpoint.

29.6.1.3 A space sensor shall allow the FAS to monitor the temperature in the areas served by the air handler unit and modulate the auxiliary heating equipment output to maintain the occupied/unoccupied setpoint.

29.6.1.4 The integral CO_2 sensor built into the air handler unit shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.6.1.5 During unoccupied periods, the unit shall shut down. At outdoor temperatures lower than $12^{O}C$, the space sensors shall activate and modulate the auxiliary heating equipment as required to maintain the unoccupied setpoint.

29.6.2 Graphical representation

29.6.2.1 Programmed space setpoint, actual space setpoint.

29.6.2.2 Air handler unit as a block, programmed/actual status of the fan, status of the heat exchanger (status for each heating stage if multiple stages available), discharged air temperature, return air temperature, CO_2 ppm setpoint/actual value, position of O/A damper

29.6.3 Alarms

- discrepancy between fan programmed status and actual status
- failure of any heating stage to operate when called for
- $+/-5^{O}C$ difference between programmed and actual space temperature setpoint.
- $+/-5^{O}C$ difference between programmed and actual discharged air setpoint.
- +200 ppm CO_2 concentration higher than the setpoint

29.7 **Packaged Rooftop Units – Electric Cooling/Gas Heating**

29.7.1 Sequencing

29.7.1.1 During occupied hours the supply fan shall operate continuously. The fresh air dampers shall open to the minimum position.

29.7.1.2 A space sensor shall allow the FAS to monitor the temperature in the areas served by the rooftop unit. If the space temperature rises above the cooling occupied setpoint, the DX cooling section shall be enabled and shall modulate as required to maintain the setpoint. If the space temperature drops below the heating occupied setpoint, the gas fired heat exchanger shall be enabled and shall modulate as required to maintain the setpoint.

29.7.1.3 The internal controls of the rooftop unit shall enable the economizer cycle (free cooling) based on differential between the return air temperature and outdoor air temperature. All economizer sections shall be equipped with power exhauster fans operated by the integral controls of the equipment.

29.7.1.4 The integral CO_2 sensor built into the rooftop unit shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.7.1.5 During unoccupied periods and outdoor temperatures higher than $12^{O}C$, the unit shall shut down. During unoccupied periods and outdoor temperatures lower than $12^{O}C$, the unit shall operate only as necessary to maintain the heating unoccupied setpoint. During unoccupied hours, the fresh air damper shall remain fully closed and the fan shall operate only on a call for heat (Auto mode).

29.7.2 Graphical representation

29.7.2.1 Programmed space setpoint, actual space setpoint.

29.7.2.2 Rooftop unit as a block, programmed/actual status of the fan, status of the DX section (status for each DX section, as applicable if multiple DX stages available), status of the heat exchanger (status for each heating stage if multiple stages available), discharged air temperature, return air temperature, CO_2 ppm setpoint/actual value, position of O/A damper

29.7.3 Alarms

- discrepancy between fan programmed status and actual status
- failure of any DX stage to operate when called for
- failure of any heating stage to operate when called for
- $+/-5^{O}C$ difference between programmed and actual space temperature setpoint.
- +200 ppm CO_2 concentration higher than the setpoint

29.8 **Packaged Rooftop Units with VVT or By-Pass Boxes Terminals**

29.8.1 Sequencing

29.8.1.1 During occupied hours the supply fan shall operate continuously. The fresh air dampers shall open to the minimum position.

29.8.1.2 Cooling mode shall be defined as the operation of the equipment at outdoor temperatures above 12^{O}C. Heating mode shall be defined as the operation of the equipment at outdoor temperatures lower than 12^{O}C.

29.8.1.3 A duct sensor shall allow the FAS to monitor the temperature of the air returning to the rooftop unit. If the return temperature rises above the cooling mode setpoint, the DX cooling section shall be enabled and shall modulate as required to maintain the setpoint. If the return temperature drops below the heating mode occupied setpoint, the gas fired heat exchanger shall be enabled and shall modulate as required to maintain the setpoint.

29.8.1.4 Space sensors shall allow the FAS to monitor the temperature in each area served by a terminal unit. The terminal units shall modulate the air supply to each zone as required to maintain the occupied heating/cooling setpoints. In heating mode, a rise in space temperature above the setpoint will lead to a decrease in air flow and vice-versa. In cooling mode, a rise in space temperature above the setpoint will lead to an increase in air flow and viceversa.

29.8.1.5 The excess air not supplied to the spaces while the terminal units are modulating, shall return to the rooftop unit either released by the individual by-pass damper of the terminal units or by the central by-pass damper actuated by the duct pressure sensor.

29.8.1.6 The internal controls of the rooftop unit shall enable the economizer cycle (free cooling) based on differential between the return air temperature and outdoor air temperature. All economizer sections shall be equipped with power exhauster fans operated by the integral controls of the equipment.

29.8.1.7 The integral CO_2 sensor built into the rooftop unit shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.8.1.8 During unoccupied periods and outdoor temperatures higher than 12^{O}C, the unit shall shut down. During unoccupied periods and outdoor temperatures lower than 12^{O}C, the unit shall operate only if any of the zones calls for heat to maintain the setback setpoint. During unoccupied hours, the fresh air damper shall remain fully closed and the fan shall operate only on a call for heat (Auto mode).

29.8.2 Graphical representation

29.8.2.1 Each programmed space setpoint, actual space setpoint.

29.8.2.2 Rooftop unit as a block, operation mode (heating or cooling), programmed/actual status of the fan, status of the DX section (status for each DX section, as applicable if multiple DX stages available), status of the heat exchanger (status for each heating stage if multiple stages available), discharged air temperature, programmed/actual return air temperature, CO_2 ppm setpoint/actual value, position of O/A damper, position of central by-pass damper (where applicable), duct static pressure (where applicable).

29.8.3 Alarms

- discrepancy between fan programmed status and actual status
- discrepancy between system programmed and actual operation mode
- failure of any DX stage to operate when called for
- failure of any heating stage to operate when called for
- +/-5^{O}C difference between programmed and actual space temperature setpoint.
- +/-5^{O}C difference between programmed and actual return temperature setpoint.
- +200 ppm CO_2 concentration higher than the setpoint

29.9 **Packaged Rooftop Units with VVT or By-Pass Boxes Terminals – and Auxiliary Space Heating (Reheat Coils or Perimeter Baseboards)**

29.9.1 Sequencing

29.9.1.1 During occupied hours the supply fan shall operate continuously. The fresh air dampers shall open to the minimum position.

29.9.1.2 Cooling mode shall be defined as the operation of the equipment at outdoor temperatures above 12^{O}C. Heating mode shall be defined as the operation of the equipment at outdoor temperatures lower than 12^{O}C.

29.9.1.3 A duct sensor shall allow the FAS to monitor the temperature of the air returning to the rooftop unit. If the return temperature rises above the cooling mode setpoint, the DX cooling section shall be enabled and shall modulate as required to maintain the setpoint. If the return temperature drops below the heating mode occupied setpoint, the gas fired heat exchanger shall be enabled and shall modulate as required to maintain the setpoint.

29.9.1.4 Space sensors shall allow the FAS to monitor the temperature in each area served by a terminal unit. The terminal units shall modulate the air supply to each zone as required to maintain the occupied heating/cooling setpoints.

29.9.1.5 In cooling mode, a rise in space temperature above the setpoint will lead to an increase in air flow and viceversa. In heating mode, the terminal device shall supply only the minimum air flow to the space, determined such as to maintain the code ventilation requirements. The auxiliary heating equipment sdhall modulate as required to maintain the heating setpoint.

29.9.1.6 The excess air not supplied to the spaces while the terminal units are modulating or in heating mode shall return to the rooftop unit either released by the individual by-pass damper of the terminal units or by the central by-pass damper actuated by the duct pressure sensor.

29.9.1.7 The internal controls of the rooftop unit shall enable the economizer cycle (free cooling) based on differential between the return air temperature and outdoor air temperature. All economizer sections shall be equipped with power exhauster fans operated by the integral controls of the equipment.

29.9.1.8 The integral CO_2 sensor built into the rooftop unit shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.9.1.9 During unoccupied periods and outdoor temperatures higher than $12^{O}C$, the unit shall shut down.

29.9.1.10 During unoccupied periods and outdoor temperatures lower than $12^{O}C$, if the auxiliary space heating equipment is not duct-mounted, the rooftop unit shall shut down. The auxiliary equipment shall modulate as required to maintain the setback temperature.

29.9.1.11 During unoccupied periods and outdoor temperatures lower than $12^{O}C$, if the auxiliary space heating equipment is duct mounted, the unit shall operate only if any of the zones calls for heat to maintain the setback setpoint. During unoccupied hours, the fresh air damper shall remain fully closed and the fan shall operate only on a call for heat (Auto mode).

29.9.2 Graphical representation

29.9.2.1 Each programmed space setpoint, actual space setpoint.

29.9.2.2 Auxiliary equipment status in each space

29.9.2.3 Discharged air downstream of auxiliary heating devices (if duct-mounted)

29.9.2.4 Rooftop unit as a block, operation mode (heating or cooling), programmed/actual status of the fan, status of the DX section (status for each DX section, as applicable if multiple DX stages available), status of the heat exchanger (status for each heating stage if multiple stages available), discharged air temperature, programmed/actual return air temperature, CO_2 ppm setpoint/actual value, position of O/A damper, position of central by-pass damper (where applicable), programmed/actual duct static pressure (where applicable).

29.9.3 Alarms

- discrepancy between fan programmed status and actual status
- discrepancy between system programmed and actual operation mode
- failure of any DX stage to operate when called for
- failure of any central heating stage to operate when called for
- failure of any auxiliary heating device to operate when called for
- +/-5^{O}C difference between programmed and actual space temperature setpoint.
- +/-5^{O}C difference between programmed and actual return temperature setpoint.
- +200 ppm CO_2 concentration higher than the setpoint

29.10 **VAV Air Handling Unit**

29.10.1 Sequencing

29.10.1.1 During occupied hours the supply fan shall operate continuously. Where applicable, the return fan shall be hard-wire interlocked with the supply-fan. The fresh air dampers shall open to the minimum position.

29.10.1.2 Cooling mode shall be defined as the operation of the equipment at outdoor temperatures above 12^{O}C. Heating mode shall be defined as the operation of the equipment at outdoor temperatures lower than 12^{O}C.

29.10.1.3 Duct sensors shall allow the FAS to monitor the temperature of the air discharged and returning to the air handler. In cooling mode, the air handler cooling section (DX or chilled water) shall modulate as required to maintain the discharged air at the cooling setpoint. In heating mode, the air handler heating section (hot water/glycol or gas fired) shall modulate as required to maintain the discharged air at the heating setpoint

29.10.1.4 The internal controls of the air handler shall enable the economizer cycle (free cooling) based on differential between the return air temperature and outdoor air temperature. All economizer sections shall be equipped with power exhauster fans operated by the integral controls of the equipment.

29.10.1.5 The integral CO_2 sensor mounted in the return ductwork shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.10.1.6 Space sensors shall allow the FAS to monitor the temperature in each area served by a terminal VAV unit. The terminal units shall modulate the air supply to each zone as required to maintain the occupied heating/cooling setpoints. In heating mode, a rise in space temperature above the setpoint will lead to a decrease in air flow and vice-versa. In cooling mode, a rise in space temperature above the setpoint will lead to an increase in air flow and viceversa.

29.10.1.7 A duct static pressure sensor shall modulate the supply fan RPM via a Variable Frequency Drive (VFD) to maintain the pressure setpoint. A separate VFD shall operate the return fan and shall be programmed to track the supply fan; where applicable, a constant flow difference between the supply and return flows shall be maintained by using the fan laws when programming the VFDs.

29.10.1.8 During unoccupied periods and outdoor temperatures higher than $12^{O}C$, the unit shall shut down. During unoccupied periods and outdoor temperatures lower than $12^{O}C$, the unit shall operate only if any of the zones calls for heat to maintain the setback setpoint. During unoccupied hours, the fresh air damper shall remain fully closed, all VAV boxes will remain at minimum flow position and the fan shall operate only on a call for heat (Auto mode).

29.10.2 Graphical representation

29.10.2.1 Each programmed space setpoint, actual space setpoint.

29.10.2.2 Each VAV box min/max. air flow setpoints/actual air flow

29.10.2.3 Air handling unit as a block, operation mode (heating or cooling), programmed/actual status of the fan(s), % of max. supply flow, % of max. return flow, status of the cooling section (DX stages or position of hydronic valve), status of the heating section (gas heat exchanger stages or position of hydronic valve), programmed/actual discharged air temperature, actual return air temperature, CO_2 ppm setpoint/actual value, programmed/actual duct static pressure, position of O/A damper.

29.10.3 Alarms

- discrepancy between fan(s) programmed status and actual status
- discrepancy between system programmed and actual operation mode
- failure of any DX stage or cooling valve to operate when called for
- failure of any heating stage or heating to operate when called for
- +/-5^{O}C difference between programmed and actual space temperature setpoint.
- +/-5^{O}C difference between programmed and actual supply temperature setpoint.
- +/-125 Pa difference between programmed and actual duct static pressure
- +200 ppm CO_2 concentration higher than the setpoint

29.11 VAV Air Handling Unit + Auxiliary Heating (Reheat Coils or Perimeter Baseboards)

29.11.1 Sequencing

29.11.1.1 During occupied hours the supply fan shall operate continuously. Where applicable, the return fan shall be hard-wire interlocked with the supply-fan. The fresh air dampers shall open to the minimum position.

29.11.1.2 Cooling mode shall be defined as the operation of the equipment at outdoor temperatures above 12^{O}C. Heating mode shall be defined as the operation of the equipment at outdoor temperatures lower than 12^{O}C.

29.11.1.3 Duct sensors shall allow the FAS to monitor the temperature of the air discharged and returning to the air handler. In cooling mode, the air handler cooling section (DX or chilled water) shall modulate as required to maintain the discharged air at the cooling setpoint. In heating mode, the air handler heating section (hot water/glycol or gas fired) shall modulate as required to maintain the discharged air at the heating setpoint.

29.11.1.4 The internal controls of the air handler shall enable the economizer cycle (free cooling) based on differential between the return air temperature and outdoor air temperature. All economizer sections shall be equipped with power exhauster fans operated by the integral controls of the equipment.

29.11.1.5 The integral CO_2 sensor mounted in the return ductwork shall modulate the fresh air dampers beyond the minimum position as required to maintain the CO_2 ppm setpoint.

29.11.1.6 Space sensors shall allow the FAS to monitor the temperature in each area served by a terminal VAV unit. In cooling mode, the terminal units shall modulate the air supply

to each zone as required to maintain the occupied cooling setpoint (a rise in space temperature above the setpoint will lead to an increase in air flow and vice-versa). In heating mode, the VAV boxes shall remain closed at the minimum position determined such as to keep the ventilation rates at code required levels. The space heating setpoint shall be maintained by modulation of the auxiliary heating equipment.

29.11.1.7 A duct static pressure sensor shall modulate the supply fan RPM via a Variable Frequency Drive (VFD) to maintain the pressure setpoint. A separate VFD shall operate the return fan and shall be programmed to track the supply fan; where applicable, a constant flow difference between the supply and return flows shall be maintained by using the fan laws when programming the VFDs.

29.11.1.8 During unoccupied periods and outdoor temperatures higher than $12^{O}C$, the unit shall shut down.

29.11.1.9 For systems equipped with perimeter baseboards, at temperatures lower than $12^{O}C$ the unit shall shut down; the auxiliary baseboard heaters will modulate as required to maintain the unoccupied setback setpoint.

29.11.1.10 For systems equipped with in-duct reheat coils, during unoccupied periods and outdoor temperatures lower than $12^{O}C$, the unit shall operate only if any of the zones calls for heat to maintain the setback setpoint. The central heating section of the unit shall not be enabled and all VAV boxes will remain locked at minimum flow setting; the setback setpoint in the area calling for heat shall be maintained by modulating the respective reheat coil output. During unoccupied hours, the fresh air damper shall remain fully closed and the fan shall operate only on a call for heat (Auto mode).

29.11.2 Graphical representation

29.11.2.1 Each programmed space setpoint, actual space setpoint.

29.11.2.2 Each VAV box min/max. air flow setpoints/actual air flow, discharged air temperature (if equipped with reheat coil)

29.11.2.3 Status of each auxiliary heating device

29.11.2.4 Air handling unit as a block, operation mode (heating or cooling), programmed/actual status of the fan(s), % of max. supply flow, % of max. return flow, status of the cooling section (DX stages or position of hydronic valve), status of the heating section (gas heat exchanger stages or position of hydronic valve), programmed/actual discharged air temperature, actual return air temperature, CO_2

ppm setpoint/actual value, programmed/actual duct static pressure, position of O/A damper.

29.11.3 Alarms

- Discrepancy between fan(s) programmed status and actual status
- Discrepancy between system programmed and actual operation mode
- failure of any DX stage or cooling valve to operate when called for
- failure of any heating stage or heating to operate when called for
- failure of any auxiliary heating equipment to operate when called for
- +/-5^{O}C difference between programmed and actual space temperature setpoint.
- +/-5^{O}C difference between programmed and actual supply temperature setpoint.
- +/-125 Pa difference between programmed and actual duct static pressure
- +200 ppm CO_2 concentration higher than the setpoint

29.12 **Split Type Heat Pump (single condenser + multiple evaporators)**

29.12.1 Sequencing

29.12.1.1 The heat pump shall operate as required to maintain the indoor setpoint in each space equipped with an evaporator.

29.12.1.2 Each space equipped with an evaporator shall be equipped with a FAS sensor which shall determine the heating/cooling and occupied/unoccupied setpoints.

29.12.1.3 The heat pump system shall be equipped with a controller which shall automatically determine which evaporators are working in heating mode and which are to operate in cooling mode.

29.12.2 Graphical Representation

29.12.2.1 The outdoor condenser and its status.

29.12.2.2 Each indoor evaporator status

29.12.2.3 Each indoor space programmed/actual temperature

29.12.3 Alarms

- +/-5^{O}C difference between programmed and actual space temperature setpoint.

29.13 Split Type Heat Pump (single condenser + multiple evaporators) and Auxiliary Heating

29.13.1 Sequencing

29.13.1.1 The heat pump shall operate as required to maintain the indoor setpoint in each space equipped with an evaporator.

29.13.1.2 Each space equipped with an evaporator shall be equipped with a FAS sensor which shall determine the heating/cooling and occupied/unoccupied setpoints.

29.13.1.3 The heat pump system shall be equipped with a controller which shall automatically determine which evaporators are working in heating mode and which are to operate in cooling mode.

29.13.1.4 If any evaporator unit operates in heating mode and the space setpoint is not achieved within 15 minutes, the auxiliary heating equipment (baseboard, forced flow heater, unit heater), will be energized and will modulate as required to maintain the setpoint

29.13.2 Graphical Representation

29.13.2.1 The outdoor condenser and its status.

29.13.2.2 Each indoor evaporator status

29.13.2.3 Each auxiliary heating equipment status

29.13.2.4 Each indoor space programmed/actual temperature

29.13.3 Alarms

- +/-5^{O}C difference between programmed and actual space temperature setpoint.

29.14 CO/NOx Monitoring System

29.14.1 Sequencing

29.14.1.1 Upon detection of CO or NOx in any zone at the lower ppm threshold concentration, the detection controller will start the VFD-equipped exhaust fan and make-up air fan low speed. The heating section of the make-up air unit will modulate as required to maintain the discharged air at a pre-set value.

29.14.1.2 If the CO or NOx ppm in the affected zone continues to rise, the controller shall ramp up the RPMs of the exhaust fan and the make-up air fan; the make-up air heat exchanger will continue to modulate to maintain the discharged air at the pre-set value.

29.14.1.3 If the exhaust fan and make-up air unit serving the affected area operate at maximum RPM for more than 5 minutes (adjustable), the FAS shall activate the audio-visual alarms in the area, all work activity will cease and preparations shall be made for the evacuation of the staff.

29.14.2 Graphical Representation

29.14.2.1 The CO/NOx reading of each sensor.

29.14.2.2 The status of each exhaust fan (programmed/actual), the % RPM of the exhaust fan when fan is activated.

29.14.2.3 Each make-up air unit as a block indicating status of supply fan (programmed/actual), status of heating section (where multiple stages are involved, status of each stage), the % RPM of the make-up air fan when unit is activated, the discharged air temperature of each make-up air system, when the unit is activated.

29.14.3 Alarms

- Activation of any exhaust fan/make-up air unit in any zone.
- Failure of any exhaust fan/make-up air unit to operate when called for by the monitoring controller.
- Discharged make-up air +/-5^{O}C deviation from setpoint when any make-up air unit is running.
- Activation of the audio-visual alarms calling for the evacuation of staff.

29.15 **Gas-Fired Boiler Heating Plant**

29.15.1 Sequencing

29.15.1.1 The FAS outdoor air sensor shall enable/disable the heating plant when the temperature drops or rises above a pre-determined setpoint for longer than 30 minutes.

29.15.1.2 When the plant is enabled, the lead primary pump will start and run throughout the heating season. The lead/lag status of the primary pumps shall alternate each 168 hrs. of runtime.

29.15.1.3 Upon proof of flow in the primary loop, the lead boiler shall start at low fire and modulate as required to maintain the primary loop setpoint. The lead/lag status of the primary pumps shall alternate each 168 hrs. of runtime.

29.15.1.4 If the lead boiler operates at maximum firing rate for more than 15 minutes and the primary return setpoint is not achieved, the lag boiler will start firing and modulate as required to meet the setpoint. Upon reaching the setpoint, the boilers will turn off in a first on/last off sequence

29.15.1.5 The lead secondary pump will start and run continuously throughout the heating season; the lead/lag status of the secondary pumps shall alternate each 168 hrs. of runtime.

29.15.1.6 The 3-way mixing valve at the interface between the primary and secondary loops shall modulate to maintain the secondary loop return water at a dynamic setpoint. The dynamic retun setpoint in the secondary loop will be adjusted by the FAS based on outdoor temperature. The adjustment shall be linear and its slope will depend on the type of building and the type of distributed heating equipment used.

29.15.1.7 Where applicable: VFD devices on the secondary loop pumps shall modulate the pumps RPMs such as to maintain the pre-set pressure differential in the secondary loop.

29.15.2 Graphical Representation

29.15.2.1 Each boiler, complete with programmed/actual status.

29.15.2.2 Each pump complete with programmed/actual status.

29.15.2.3 Programmed/Actual values of the primary loop supply and return temperatures

29.15.2.4 Programmed/Actual values of the secondary loop supply and return temperatures.

29.15.2.5 % position of the 3-way mixing valve open to the secondary loop.

29.15.2.6 % of the secondary pumps VFD setting (where applicable)

29.15.3 Alarms

- +/-5^{O}C difference between programmed and actual primary loop return setpoint.
- +/-5^{O}C difference between programmed and actual secondary loop return setpoint
- Failure of any lead pump (lag pump shall start automatically)
- Failure of any lead boiler (lag boiler shall start automatically)
- Primary loop temperature lower than 30^{O}C or higher than 95^{O}C.
- Secondary loop temperature differential higher than 20^{O}C or lower than 5^{O}C.
- Pressure differential in the secondary loop exceeds +/-10% of the setpoint.

29.16 **Gas-Fired Snow Melting Boiler Heating Plant**

29.16.1 Sequence of operations, alarms and graphical representation included in the Snow Melting DRM document

29.17 **Indoor Lighting**

29.17.1 Sequencing

29.17.1.1 The lighting for each zone shall be turned on or off based on a time-of-day Owner defined schedule.

29.17.1.2 Occupant Override: A timed local override control will allow an occupant to override the schedule of any particular zone and turn the lighting on for an adjustable period of time. At the expiration of this time, control of the lighting in the respective zone will automatically return to the schedule.

29.17.1.3 Warning Flash: The output will cycle off (flash) 5 times (adjustable) to warn occupants in the lighted zone when the lights are about to turn off. This flashing will occur 5 minutes (adjustable) before the lights turn off.

29.17.2 Graphical Representation

29.17.2.1 Each zone lighting programmed/actual status.

29.17.3 Alarms

- Output Runtime Exceeded: Lighting runtime exceeds a user definable limit (adjustable).

29.18 **Outdoor Lighting**

29.18.1 Sequencing

29.18.1.1 The lighting for each outdoor zone shall be turned on or off based on a schedule that is Owner defined and takes into account the following:

Local sunrise/sunset times
Train/Buses leaving/departure times.

29.18.2 Graphical Representation

29.18.2.1 Each zone lighting programmed/actual status.

29.18.3 Alarms

- Output Runtime Exceeded: Lighting runtime exceeds a user definable limit (adjustable).

29.19 **Simpex Sanitary/Storm Ejectors**

29.19.1 Sequencing

29.19.1.1 The operation of simplex sanitary/storm ejectors shall be controlled by the built-in panel that forms an integral part of the ejector system. All sensors from the floats or ultra-sonic probes shall be connected to the control panel and the pumps shall operate accordingly, to maintain the fluid in the sump pit between two pre-set levels.

29.19.1.2 The control panel shall determine the start/stop operation of the pumps based on fluid level in the pit.

29.19.1.3 All connections to the BAS shall be for status read-only information and for alarms.

29.19.1.4 Separately, high level fluid alarms shall be generated and sent to the GO Transit/Metrolinx security monitoring company (currently Chubb)

29.19.1.5 The pumps control panel shall interface with the BAS to allow the read-only information to be graphically displayed as outlined below.

29.19.2 Graphical representation

29.19.2.1 Each sump pump status

29.19.3 Alarms

29.19.3.1 Any pump failure, high level fluid alarm

29.20 **Duplex Sanitary/Storm Ejectors**

29.20.1 Sequencing

29.20.1.1 The operation of duplex sanitary/storm ejectors shall be controlled by the built-in panel that forms an integral part of the ejector system. All sensors from the floats or ultra-sonic probes shall be connected to the control panel and the pumps shall operate accordingly, to maintain the fluid in the sump pit between two pre-set levels.

29.20.1.2 The control panel shall determine and alternate the lead/lag status of the pumps, the conditions under which both pumps have to operate simultaneously based on the fluid level in the pit.

29.20.1.3 All connections to the BAS shall be for status read-only information and for alarms.

29.20.1.4 Separately, high level fluid alarms shall be generated and sent to the GO Transit/Metrolinx security monitoring company (currently Chubb)

29.20.1.5 The pumps control panel shall interface with the BAS to allow the read-only information to be graphically displayed as outlined below.

29.20.2 Graphical representation

29.20.2.1 Each sump pump status

29.20.3 Alarms

29.20.3.1 Any pump failure, high level fluid alarm