J∆S Engineering Suite

Module Guide: Controls & Sequences of Operations

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JS Engineering Solutions

Version: 1.1 **Applicable Standards:** ASHRAE Guideline 36-2021, ASHRAE Standard 90.1-2022, ASHRAE Standard 62.1-2022, NFPA 90A, NFPA 92 **Last Updated:** February 2026

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1. Overview

What Are Sequences of Operations?

A Sequence of Operations (SOO) is the written description of how every piece of HVAC equipment in a building is intended to operate under all conditions — startup, occupied, unoccupied, standby, alarm, and failure. The SOO is the single most important document a controls contractor receives. It defines the logic that the Building Automation System (BAS) programmer encodes into the DDC controllers. A vague or incomplete SOO results in comfort complaints, wasted energy, and commissioning delays.

The J∆S Engineering Suite generates complete, specification-ready sequences of operations for every major equipment type. These sequences follow ASHRAE Guideline 36-2021, "High-Performance Sequences of Operation for HVAC Systems," which is the industry's gold-standard reference for DDC control logic. Guideline 36 provides rigorously tested, energy-efficient sequences that have been validated through simulation and field monitoring.

ASHRAE Guideline 36-2021

ASHRAE Guideline 36 was first published in 2018 and substantially updated in 2021. It provides standardized sequences for:

- Multiple-zone VAV air handling units (heating and cooling)
- Single-zone VAV and constant-volume air handling units
- Dual-fan dual-duct air handling units
- VAV terminal units with and without reheat
- Chilled water plants
- Hot water plants
- Zone-level control logic

By adopting Guideline 36 sequences, the J∆S Engineering Suite ensures that every project benefits from optimized control strategies including supply air temperature reset, static pressure reset, economizer logic with differential enthalpy, trim-and-respond logic, and demand-controlled ventilation.

BACnet DDC Systems

All sequences generated by the J∆S Engineering Suite assume a BACnet-based Direct Digital Control (DDC) system. BACnet (ASHRAE Standard 135) is the dominant open protocol for building automation. The generated points lists, alarm definitions, and interlock tables are structured for BACnet object types:

- **AI** (Analog Input) — sensor readings (temperature, pressure, humidity)
- **AO** (Analog Output) — modulating actuator commands (valve position, VFD speed)
- **DI** (Digital Input) — binary status signals (run status, alarm, proof of flow)
- **DO** (Digital Output) — binary commands (start/stop, open/close)

The controls modules in the J∆S Engineering Suite generate both the narrative sequence text and the corresponding BACnet points list, ensuring consistency between the specification and the as-built controller programming.

Why Sequences Matter

Poor sequences are the number-one cause of building performance gaps. Studies by PNNL and LBNL have shown that buildings with well-written, commissioning-verified sequences use 20-40% less energy than buildings with vague or poorly implemented controls. The most common deficiencies include:

- Missing economizer enable/disable logic (building uses mechanical cooling when free cooling is available)
- No supply air temperature reset (fixed 55 degrees F year-round wastes reheat energy)
- No static pressure reset (fan runs at full speed even when zones need minimal airflow)
- Missing unoccupied mode sequences (systems run 24/7 instead of on schedule)
- No interlock logic between dependent equipment (pumps run with no load, boilers fire with no flow)

The J∆S Engineering Suite eliminates these deficiencies by generating complete sequences for every equipment type and operating mode.

2. Getting Started in J∆S Engineering Suite

Creating a Controls Project

1. Launch J∆S Engineering Suite and log in.

2. Open an existing project or create a new one via File > New Project.

3. Navigate to the Controls module from the dashboard or the sidebar under "Controls & Sequences."

4. The Controls module presents a tabbed interface with the following tabs:

- **Systems** — Define AHUs, terminal units, plant equipment
- **Sequences** — Auto-generate and edit sequences per equipment
- **Points List** — BACnet points list generation
- **Interlocks** — Equipment interlock matrix
- **Schedules** — Occupancy and operating schedules
- **Export** — Export to CSI specification format

Defining Systems

In the **Systems** tab, add equipment by clicking "Add Equipment" and selecting the type:

Equipment Type	Subtypes Available
Air Handling Unit	VAV Multi-Zone, VAV Single-Zone, CV, DOAS, MAU
Terminal Unit	VAV w/ Reheat, VAV No Reheat, Fan-Powered, Series/Parallel
Fan Coil Unit	2-Pipe, 4-Pipe, Vertical, Horizontal
Packaged RTU	DX Cooling, Heat Pump, Gas/Electric

Equipment Type	Subtypes Available
VRF System	Heat Recovery, Heat Pump
Chiller	Air-Cooled, Water-Cooled, Absorption
Boiler	Condensing, Non-Condensing, Dual-Fuel
Cooling Tower	Open, Closed, Hybrid
Pump	Constant Speed, Variable Speed, Inline, Split-Case
Exhaust Fan	General, Kitchen Hood, Lab, Parking Garage
Heat Recovery	Enthalpy Wheel, Plate HX, Run-Around, Heat Pipe

For each equipment item, fill in the design parameters: capacity, airflow, motor HP, VFD, sensors, and zones served. The software auto-populates typical values based on the selected type and capacity range.

Generating Sequences

1. Select an equipment item in the Systems tab.

2. Click **"Generate Sequence"** in the toolbar.

3. The software produces a complete narrative sequence following ASHRAE Guideline 36 methodology.

4. The generated sequence appears in the Sequences tab, organized by equipment tag.

5. Each sequence includes: startup, occupied mode, unoccupied mode, standby mode, alarms, safety shutdowns, and seasonal changeover.

6. Edit any section by clicking on it — the editor supports rich text with tables.

Generating Points Lists

1. Switch to the **Points List** tab.

2. Click **"Generate All Points"** to create BACnet points for every equipment item.

3. The points list includes: point name, BACnet type (AI/AO/DI/DO), description, engineering units, range, alarm limits, and trend interval.

4. Export to Excel (CSV) or PDF using the Export button.

Exporting to Specification Format

1. Switch to the **Export** tab.

2. Select **CSI 23 09 00** (Instrumentation and Control for HVAC) format.

3. Choose which equipment sequences to include.

4. Click **"Export Specification"** to generate a Word-compatible document.

5. The export includes Part 1 (General), Part 2 (Products), and Part 3 (Execution) formatted per CSI MasterFormat.

3. AHU Sequence (ASHRAE Guideline 36-2021)

This section describes the complete sequence for a multiple-zone VAV air handling unit with hot water preheat, chilled water cooling, and an airside economizer.

3.1 Startup Sequence

Before the supply fan starts, the following pre-start checks shall be satisfied:

1. **Filter differential pressure verified.** The filter DP transmitter must read below the high-limit alarm setpoint (1.0" w.c. for MERV-13 filters at clean condition). If the filter DP exceeds the alarm threshold, the AHU shall not start and a "Dirty Filter" alarm shall be generated.
2. **Smoke detector clear.** The duct-mounted smoke detector in both the supply and return air streams shall indicate no smoke. If either detector is in alarm, the AHU shall remain off and a "Smoke Detected" alarm shall be sent to the BMS.
3. **Damper end-switch confirmed.** The outdoor air damper, return air damper, and exhaust/relief damper shall be driven to their pre-start positions (OA damper closed, RA damper open). End-switch confirmation shall be received within 60 seconds or a "Damper Failure" alarm is generated.
4. **Freeze stat clear.** The low-temperature limit (freeze stat) controller must be in a normal (non-tripped) state. The freeze stat trips at 38 degrees F and requires manual reset.
5. **VFD ready.** The supply fan variable frequency drive (VFD) shall report a "Ready" status, indicating no active faults.

Once all five pre-start conditions are satisfied, the supply fan VFD shall ramp from 0% to minimum speed (20% of design) over a 30-second ramp period. The return/exhaust fan VFD shall start simultaneously at an offset of minus 10% from supply fan speed to maintain building pressurization.

3.2 Occupied Mode

During occupied hours (as defined by the BMS schedule), the AHU shall operate as follows:

Supply Air Temperature (SAT) Control

The supply air temperature setpoint defaults to **55 degrees F**. A PID control loop modulates the chilled water valve to maintain the measured supply air temperature at setpoint. PID tuning parameters:

Parameter	Value
Proportional band	4 degrees F
Integral time	3 minutes
Derivative time	0 minutes (PI only)
Output range	0% (valve closed) to 100% (valve full open)

When the supply air temperature exceeds setpoint by more than 2 degrees F and the chilled water valve is fully open, a "High SAT" alarm shall be generated after a 5-minute delay.

When the supply air temperature drops below 45 degrees F, regardless of operating mode, a "Low SAT" alarm shall be generated immediately and the hot water preheat valve shall drive to 100% open.

Duct Static Pressure Control

The duct static pressure setpoint defaults to **two-thirds (2/3) of design static pressure**. For a system designed for 2.5" w.c. total external static, the initial setpoint is 1.67" w.c. The supply fan VFD speed modulates via a PI loop to maintain the measured duct static pressure at setpoint.

The static pressure sensor shall be located approximately two-thirds of the distance down the longest duct run from the AHU, as recommended by ASHRAE Guideline 36.

PI tuning for duct static pressure:

Parameter	Value
Proportional band	0.5" w.c.
Integral time	1.5 minutes
Derivative time	0 minutes
Output range	20% (minimum fan speed) to 100%

Economizer Operation

The airside economizer logic determines the outdoor air (OA) damper position to provide free cooling when outdoor conditions are favorable:

1. Enable condition: The economizer shall be enabled when the outdoor air temperature (OAT) is less than the return air temperature (RAT) minus 2 degrees F. That is: OAT < (RAT - 2 degrees F). This 2 degree F differential prevents short-cycling of the economizer at the changeover point.

2. Modulation: When the economizer is enabled, the OA damper modulates open (and the RA damper modulates closed) as the first stage of cooling. The OA damper position is modulated by the SAT PID loop. If the OA damper reaches 100% open and the SAT still exceeds setpoint, the chilled water valve begins to modulate as the second stage of cooling.

3. Disable condition: When OAT exceeds (RAT - 2 degrees F), the economizer is disabled. The OA damper returns to its minimum position for ventilation.

4. High-limit shutoff: Per ASHRAE 90.1-2022 Table 6.5.1.1.3, for Climate Zones 1A through 4A, the economizer high-limit shutoff is 75 degrees F (fixed drybulb). For Climate Zones 5A through 8, the high-limit shutoff is 70 degrees F. Above the high-limit, the economizer is locked out regardless of the differential calculation.

5. Differential enthalpy (humid climates): In Climate Zones 1A, 2A, and 3A, the economizer shall use differential enthalpy logic in addition to drybulb. The economizer is enabled when OA enthalpy < RA enthalpy and OA drybulb < high-limit.

Minimum Outdoor Air Tracking

The minimum outdoor air fraction shall be maintained per ASHRAE 62.1-2022 during all occupied modes. The minimum OA flow is calculated as the sum of zone-level outdoor air requirements (Vbz) adjusted by system ventilation efficiency (Ev):

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Vot = Vou / Ev
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Where Vou is the uncorrected outdoor air intake and Ev is determined by the zone with the highest Zp ratio. The OA damper minimum position shall be calibrated at commissioning to deliver at least Vot at the design supply fan speed. If an airflow measuring station is installed in the OA duct, a PI loop shall modulate the OA damper to maintain the measured OA flow at the Vot setpoint.

Heating Mode

When the mixed air temperature drops below the SAT setpoint minus 2 degrees F, the heating sequence activates:

1. First, the OA damper modulates toward minimum position (reducing cold outdoor air).
2. If the mixed air temperature continues to drop, the hot water preheat valve modulates open via a PI loop.
3. The preheat valve PI tuning: Proportional band = 5 degrees F, Integral time = 2 minutes.
4. The preheat coil leaving air temperature setpoint is 55 degrees F (matching SAT setpoint).
5. If the preheat valve reaches 100% and the SAT is still below 50 degrees F, a "Low SAT" alarm is generated.

3.3 Unoccupied Mode

During unoccupied hours:

1. **Supply and return fans:** OFF.
2. **Outdoor air damper:** CLOSED (drive to 0% and verify end-switch).
3. **Return air damper:** CLOSED.
4. **Chilled water valve:** CLOSED (0%).
5. **Hot water valve:** CLOSED (0%).

Night setback logic:

- If any zone served by this AHU reports a space temperature above **85 degrees F** (cooling setback), the AHU shall start in cooling mode with the OA damper at minimum position and the SAT setpoint at 55 degrees F. The AHU shall run until all zones are below 83 degrees F, then shut down.
- If any zone served by this AHU reports a space temperature below **55 degrees F** (heating setback), the AHU shall start in heating mode with the OA damper at minimum position and the hot water preheat/reheat valves modulating to maintain a SAT of 90 degrees F. The AHU shall run until all zones are above 58 degrees F, then shut down.

3.4 Standby Mode

During the standby period (typically 1 to 2 hours before scheduled occupancy), the AHU shall execute a pre-occupancy warm-up or cool-down cycle:

- **Warm-up:** If the average zone temperature served by this AHU is below the occupied heating setpoint (72 degrees F), the AHU starts in heating mode with the OA damper closed (100% recirculation) and the supply air temperature setpoint at 90 degrees F. The OA damper remains closed until zones reach setpoint, at which point the system transitions to occupied mode with normal ventilation.
- **Cool-down:** If the average zone temperature exceeds the occupied cooling setpoint (75 degrees F), the AHU starts in cooling mode. If the economizer enable condition is met (OAT < RAT - 2 degrees F), the OA damper opens to 100% for free cooling. Otherwise, the OA damper is at minimum and the chilled water valve modulates.

The standby period duration is adjustable from 0 to 4 hours in the BMS schedule.

3.5 Supply Air Temperature Reset

Per ASHRAE Guideline 36 trim-and-respond logic, the supply air temperature setpoint shall be reset based on zone cooling demand:

Condition	SAT Setpoint
High cooling demand (any zone calling for maximum airflow)	55 degrees F
Moderate cooling demand	55 to 65 degrees F (proportional reset)
Low cooling demand (all VAV dampers below 50%)	65 degrees F

Trim-and-respond parameters:

- Device: All VAV terminal units served by this AHU
- Trim amount: +0.2 degrees F (raise SAT setpoint)
- Respond amount: -0.3 degrees F (lower SAT setpoint)
- Maximum setpoint: 65 degrees F
- Minimum setpoint: 55 degrees F
- Sampling interval: 2 minutes

The logic evaluates how many zones have requests for cooling. If fewer than 10% of zones have active cooling requests (VAV damper above 90%), the SAT setpoint is trimmed upward. If any zone has a request, the setpoint responds downward. This gradually finds the optimal SAT that satisfies all zones with minimal energy use.

3.6 Static Pressure Reset

The duct static pressure setpoint shall be reset downward when zone dampers indicate reduced airflow demand:

Condition	SP Setpoint
Any VAV damper at 100% open for > 5 min	1.5" w.c. (design maximum)
All VAV dampers below 80%	Reset toward 0.5" w.c.
Minimum (all dampers well below design)	0.5" w.c.

Trim-and-respond parameters:

- Device: All VAV terminal units served by this AHU
- Trim amount: -0.05" w.c. (lower SP setpoint)
- Respond amount: +0.10" w.c. (raise SP setpoint)
- Maximum setpoint: 1.5" w.c.
- Minimum setpoint: 0.5" w.c.
- Sampling interval: 2 minutes

This reset strategy can reduce fan energy by 30% to 50% compared to a fixed static pressure setpoint.

3.7 AHU Alarms

Alarm	Condition	Priority	Auto-Reset
High SAT	SAT > setpoint + 5 degrees F for 5 min	Medium	Yes
Low SAT	SAT < 45 degrees F	High	Yes
Freeze Stat	Freeze stat tripped (38 degrees F)	Critical	No (manual)
High Duct SP	SP > 3.0" w.c.	High	Yes
Filter DP	Filter DP > 1.5" w.c. (MERV-13)	Low	Yes
Smoke Detection	Duct smoke detector in alarm	Critical	No (manual)
Supply Fan Fault	VFD fault or no run status after start command	Critical	No (manual)
Economizer Fault	OA damper position does not match command by > 20% for 5 min	Medium	Yes
Mixed Air Low Temp	Mixed air temp < 42 degrees F	High	Yes
Return Fan Fault	Return fan VFD fault	High	No (manual)
High Return Air Temp	RAT > 85 degrees F	Medium	Yes
Humidity High	RA humidity > 65% RH	Low	Yes

4. VAV Terminal Unit Sequence

4.1 Zone Temperature Control

Each VAV terminal unit serves a single thermal zone and modulates supply airflow and reheat capacity to maintain the zone temperature setpoint. The control operates in three modes:

Cooling Mode

When the zone temperature rises above the cooling setpoint (default 75 degrees F), the VAV damper modulates open to increase airflow. The damper position is proportional to the deviation above setpoint:

- At setpoint: damper at minimum position (30% of design CFM or OA minimum, whichever is greater)
- At setpoint + 2 degrees F: damper at 100% of design CFM

The modulation range is therefore from **100% down to 30%** of design airflow as the zone cools from 2 degrees above setpoint to setpoint.

Deadband

Between the heating setpoint (72 degrees F) and the cooling setpoint (75 degrees F), the VAV damper remains at its minimum position and the reheat valve remains closed. No active heating or cooling is provided in the deadband.

Heating Mode

When the zone temperature drops below the heating setpoint (default 72 degrees F), the reheat valve modulates to maintain the zone at the heating setpoint. The VAV damper remains at minimum airflow position during heating to avoid overcooling the zone with 55 degree F supply air.

Reheat valve PI tuning:

Parameter	Value
Proportional band	3 degrees F
Integral time	5 minutes
Derivative time	0 minutes
Output range	0% to 100%

4.2 Minimum Airflow

The minimum airflow setpoint for each VAV terminal unit is the **greatest of:**

1. 30% of the design maximum airflow

2. The zone outdoor air minimum (OA_min) per ASHRAE 62.1-2022

3. 50 CFM (absolute minimum for proper air distribution and diffuser performance)

Example: For a VAV box with a design maximum of 800 CFM serving a zone requiring 120 CFM of outdoor air:

- 30% of design = 240 CFM
- OA_min = 120 CFM
- Absolute minimum = 50 CFM
- **Minimum airflow setpoint = 240 CFM** (greatest value governs)

4.3 Reheat Staging

For VAV boxes equipped with hot water reheat coils, heating is staged as follows:

Stage 1 — Modulating Reheat:

- The VAV damper is at minimum airflow position.
- The hot water reheat valve modulates from 0% to 100% via a PI loop to maintain the zone heating setpoint.
- PI tuning: Proportional band = 3 degrees F, Integral time = 5 minutes.

Stage 2 — Increased Airflow with Reheat (if applicable):

- If Stage 1 heating cannot maintain the zone at setpoint (reheat valve at 100% for more than 10 minutes and zone temp still falling), the VAV damper opens above minimum to increase airflow through the reheat coil, up to the heating maximum airflow setpoint (typically 50% of design cooling airflow).

- The reheat valve continues to modulate at 100%.
- This stage applies only to VAV boxes sized for dual-maximum control per ASHRAE Guideline 36.

Electric Reheat Staging (where applicable):

- Stage 1: First bank ON (typically 33% capacity)
- Stage 2: Second bank ON (67% capacity)
- Stage 3: Third bank ON (100% capacity)
- A discharge air high-limit thermostat (90 degrees F) de-energizes all heating stages if exceeded.

4.4 Occupancy Response

When the zone transitions from occupied to unoccupied:

- **Unoccupied minimum airflow:** 0 CFM. The VAV damper closes fully.
- **Reheat valve:** Closed (0%).
- **Night setback:** The VAV controller monitors the zone temperature sensor. If the zone temperature exceeds 85 degrees F or drops below 55 degrees F, the VAV controller sends a request to the AHU to start in night setback mode. Once the AHU starts, the VAV damper opens and modulates to satisfy the setback setpoints.

When an occupancy sensor is installed:

- If the occupancy sensor detects presence during scheduled unoccupied hours, the zone operates in "occupied standby" mode: the VAV damper goes to minimum airflow to provide ventilation, and heating/cooling setpoints revert to occupied values.
- If the occupancy sensor detects no presence during scheduled occupied hours for 30 minutes, the zone transitions to "unoccupied standby" mode: the VAV damper reduces to 50% of minimum airflow (but not less than the OA minimum), and the deadband widens by 2 degrees F in each direction.

4.5 Dual Setpoint Adjustment

Setpoint	Default	Adjustable Range
Heating setpoint	72 degrees F	69 to 75 degrees F (+/- 3 degrees F)
Cooling setpoint	75 degrees F	72 to 78 degrees F (+/- 3 degrees F)

The minimum deadband between heating and cooling setpoints shall be 3 degrees F. If a zone-level adjustment attempts to narrow the deadband below 3 degrees F, the BMS shall enforce the minimum separation.

4.6 Fan-Powered VAV Sequences

Series Fan-Powered VAV:

- The series fan runs continuously during occupied hours at constant speed.
- It draws air from the ceiling plenum (return air) and mixes it with primary air from the AHU.
- The primary air damper modulates to control zone temperature.
- When the zone calls for heating, the reheat coil activates.

- During unoccupied hours, the series fan may run for night setback.

Parallel Fan-Powered VAV:

- The parallel fan is OFF during cooling mode. Primary air is delivered directly.
- When the zone calls for heating (zone temp < heating setpoint), the parallel fan starts and draws plenum air through the reheat coil.
- The primary air damper closes to its minimum position during heating mode.
- The parallel fan cycles OFF when the zone temperature is satisfied.

5. Fan Coil Unit Sequences

5.1 Two-Pipe Fan Coil (Heating/Cooling Changeover)

In a two-pipe system, the same piping circuit carries either chilled water or hot water depending on the season.

Seasonal Changeover:

- The building operator or BMS initiates changeover based on outdoor air temperature.
- **Switch to cooling:** When the 3-day rolling average OAT exceeds 65 degrees F.
- **Switch to heating:** When the 3-day rolling average OAT drops below 55 degrees F.
- The 10 degree F deadband between 55 and 65 degrees F prevents frequent changeovers during swing seasons.

Cooling Mode (Summer):

- The fan coil fan operates at the speed selected by the occupant (Low / Medium / High) or auto.
- The chilled water valve modulates via a PI loop to maintain zone temperature at the cooling setpoint (75 degrees F).
- If the zone temperature drops to within 1 degree F of the cooling setpoint, the valve closes.

Heating Mode (Winter):

- The hot water valve modulates via a PI loop to maintain zone temperature at the heating setpoint (72 degrees F).
- Fan speed: auto mode selects speed based on deviation from setpoint.

5.2 Four-Pipe Fan Coil (Simultaneous Heating and Cooling)

In a four-pipe system, both chilled water and hot water are available simultaneously.

Zone Control Logic:

- Zone temperature > cooling setpoint + 0.5 degrees F: CHW valve modulates open, HW valve closed.
- Zone temperature in deadband (72 to 75 degrees F): Both valves closed.
- Zone temperature < heating setpoint - 0.5 degrees F: HW valve modulates open, CHW valve closed.

Interlock: The CHW and HW valves shall never be open simultaneously. A software interlock prevents both valves from being commanded open at the same time.

Fan Speed Control (Auto Mode):

Zone Temp Deviation	Fan Speed
> 3 degrees F from setpoint	High
1.5 to 3 degrees F from setpoint	Medium
0 to 1.5 degrees F from setpoint	Low
At setpoint	Low (minimum)

Condensate Management:

- A condensate overflow float switch (DI) shuts down the fan coil if the drain pan overflows.
- A "Condensate Overflow" alarm (Priority: High) is generated.

5.3 Fan Coil Unit BACnet Points

Point Name	Type	Description
ZN_TEMP	AI	Zone temperature (degrees F)
FAN_CMD	DO	Fan start/stop command
FAN_STS	DI	Fan run status
FAN_SPD	AO	Fan speed command (0/33/66/100%)
CHW_VLV	AO	Chilled water valve (%, 4-pipe only)
HW_VLV	AO	Hot water valve (%)
COND_ALM	DI	Condensate overflow alarm

Typical FCU point count: 1 AI, 2-3 AO, 2 DI, 1 DO = 6-7 points

6. Dedicated Outdoor Air System (DOAS) Sequences

6.1 Overview

A DOAS unit conditions 100% outdoor air to a neutral supply air condition and delivers it directly to zones or to the OA connection of terminal units. The DOAS decouples ventilation from space conditioning, allowing terminal units (fan coils, radiant panels, VRF) to handle only sensible loads.

6.2 Supply Air Condition

The DOAS supply air temperature and humidity targets:

Season	Supply Air Temp	Supply Air Humidity
Cooling (OAT > 65 degrees F)	55 degrees F	< 55 grains/lb (dewpoint 48 degrees F)

Season	Supply Air Temp	Supply Air Humidity
Heating (OAT < 55 degrees F)	68 degrees F	No humidification (or 30% RH min if humidifier installed)
Swing (55-65 degrees F OAT)	60 degrees F	No active dehumidification

6.3 Cooling Sequence

1. The energy recovery wheel (if installed) pre-conditions the outdoor air.

2. A cooling coil (chilled water or DX) cools and dehumidifies the air to 55 degrees F.

3. If the cooling coil cannot reach the dewpoint target, a secondary dehumidification coil or desiccant wheel activates.

4. The supply fan delivers conditioned air to zone terminals.

DX Cooling Staging (Packaged DOAS):

Stage	Compressor	Capacity
1	Compressor 1 at low speed	33%
2	Compressor 1 at high speed	50%
3	Compressor 1 + 2 at low speed	67%
4	Compressor 1 + 2 at high speed	100%

6.4 Heating Sequence

1. The energy recovery wheel pre-warms the outdoor air.

2. A hot water coil (or gas-fired burner) heats the air to the supply temperature setpoint.

3. The supply air temperature setpoint resets based on OAT:

• OAT = 0 degrees F: SAT setpoint = 72 degrees F

• OAT = 55 degrees F: SAT setpoint = 60 degrees F

6.5 Energy Recovery Control

The energy recovery wheel rotates when the unit is in operation. Speed modulation controls the amount of energy transferred:

• **Full speed (100%):** Maximum energy recovery. Used when OAT is far from the supply setpoint.

• **Reduced speed:** When the OAT is close to the supply setpoint, the wheel speed reduces to avoid overheating or overcooling.

• **Bypass:** When OAT is between 55 and 65 degrees F and no heating or cooling is needed, the bypass damper opens and the wheel stops.

Frost Control:

• When the exhaust air temperature leaving the wheel drops below 35 degrees F, the wheel speed reduces or the bypass damper partially opens to prevent frost formation on the wheel surface.

- If the exhaust leaving temperature reaches 32 degrees F, the wheel stops and the bypass damper opens fully until the temperature rises above 38 degrees F.

7. Packaged Rooftop Unit (RTU) Sequences

7.1 DX Cooling RTU

Compressor Staging:

For a 2-stage DX RTU:

Cooling Demand	Stage
Zone temp > CSP + 1 degrees F	Stage 1 ON (low capacity)
Zone temp > CSP + 2 degrees F for 5 min with Stage 1 ON	Stage 2 ON (full capacity)
Zone temp < CSP	Stage 1 OFF (after 3-min minimum run time)

Anti-short-cycle timer: After a compressor stops, it shall not restart for at least 5 minutes to protect the compressor from liquid slugging and high head pressure.

Condenser fan: Interlocked with compressor. Fan starts 15 seconds before compressor. Fan stops 60 seconds after compressor (to dissipate residual heat from condenser coil).

7.2 Gas/Electric RTU Heating

Gas Heating Stages:

Heating Demand	Stage
Zone temp < HSP - 0.5 degrees F	Stage 1 burner ON (low fire)
Zone temp < HSP - 2 degrees F for 5 min with Stage 1 ON	Stage 2 burner ON (high fire)
Zone temp > HSP	All burners OFF (after 2-min post-purge fan run)

Safety Interlocks:

- Combustion air proving switch must close before ignition.
- Flame detection within 10-second trial for ignition.
- High-limit thermostat (200 degrees F) shuts off gas valve.
- Supply fan must be proven ON before burner ignition.

7.3 Heat Pump RTU

Reversing Valve Logic:

- Cooling mode: Reversing valve energized (standard configuration).

- Heating mode: Reversing valve de-energized.
- Minimum 5-minute delay between mode changes to allow pressures to equalize.

Defrost Sequence (Heating Mode):

- Defrost initiates when the outdoor coil temperature drops below 32 degrees F and the unit has been in heating mode for at least 30 minutes.
- The reversing valve switches to cooling mode to send hot refrigerant through the outdoor coil.
- Supplemental electric heat (if available) energizes to temper the supply air during defrost.
- Defrost terminates when the outdoor coil temperature reaches 55 degrees F or after 10 minutes maximum.
- After defrost, the reversing valve switches back to heating mode.

Auxiliary Heat (Emergency Heat):

- When the heat pump alone cannot maintain the zone temperature (zone temp drops more than 3 degrees F below heating setpoint), auxiliary electric heat stages ON.
- At OAT below the heat pump balance point (typically 30 degrees F), the heat pump may be locked out and auxiliary heat provides all heating (operator-configurable).

8. VRF/VRV System Sequences

8.1 Overview

Variable Refrigerant Flow (VRF) systems use a single outdoor condensing unit connected to multiple indoor units via refrigerant piping. The system modulates refrigerant flow to each indoor unit based on zone demand.

8.2 Cooling Mode

- Each indoor unit has a zone temperature sensor and a local controller.
- When the zone temperature exceeds the cooling setpoint, the indoor unit fan starts and the electronic expansion valve (EEV) opens to admit refrigerant.
- The outdoor unit compressor modulates via inverter drive to match the total cooling demand from all connected indoor units.
- The compressor operates between 10% and 100% capacity using variable-speed inverter technology.

8.3 Heating Mode (Heat Pump VRF)

- The outdoor unit reverses the refrigerant cycle.
- Hot refrigerant flows to indoor units calling for heating.
- The EEV at each indoor unit modulates to deliver the required heating capacity.

8.4 Heat Recovery Mode (3-Pipe VRF)

In a 3-pipe heat recovery VRF system, some indoor units can cool while others heat simultaneously:

- Zones on the south and west facades may call for cooling (solar gain).
- Zones on the north facade may call for heating (cold OAT).
- The branch selector boxes (BSBs) route refrigerant appropriately: hot gas to heating zones, liquid refrigerant to cooling zones.
- Heat rejected by cooling zones is recovered and delivered to heating zones, dramatically improving energy efficiency.
- The COP in heat recovery mode can exceed 6.0 because the system is transferring heat rather than generating it.

8.5 BMS Integration

VRF systems communicate with the BMS via a gateway (BACnet IP or Modbus to proprietary protocol). The following points are typically available:

Point	Type	Description
ZONE_TEMP	AI	Zone temperature per indoor unit
ZONE_SP	AO	Zone setpoint (writable)
MODE	AO	Operating mode (Off/Cool/Heat/Fan/Auto)
FAN_SPD	AO	Fan speed (Low/Med/High/Auto)
OUTDOOR_TEMP	AI	Outdoor unit ambient temperature
COMP_FREQ	AI	Compressor inverter frequency (Hz)
FAULT_CODE	AI	Fault code (manufacturer-specific)

9. Chiller Plant Sequence

9.1 Chiller Staging

Enable Condition for Chiller CH-1:

The lead chiller (CH-1) shall be enabled when **any** AHU chilled water valve served by this plant is greater than **90% open** for a continuous period of **10 minutes**. This prevents short-cycling caused by transient loads.

Disable Condition for Chiller CH-1:

The lead chiller shall be disabled when **all** AHU chilled water valves are less than **20% open** for a continuous period of **15 minutes**.

Staging for Multiple Chillers:

For plants with more than one chiller, the lag chiller (CH-2) shall be enabled when the lead chiller is running at or above 90% capacity for 15 minutes and any AHU chilled water valve remains above 90% open. CH-2 shall be disabled when the combined plant load drops below 40% of total plant capacity for 15 minutes.

9.2 Chilled Water Supply Temperature

The chilled water supply temperature (CHWST) setpoint defaults to **44 degrees F**. A PID loop modulates the chiller capacity (compressor loading) to maintain the CHWST at setpoint.

CHWST Reset:

Condition	CHWST Setpoint
Any AHU CHW valve > 90%	44 degrees F (design minimum)
All AHU CHW valves < 50%	48 degrees F (maximum reset)
Intermediate	Linear interpolation between 44 and 48 degrees F

This reset reduces chiller energy by raising the suction pressure, improving the coefficient of performance (COP). A 1 degree F increase in CHWST typically improves chiller efficiency by 1.5-2%.

9.3 Condenser Water Control

Cooling Tower Sequence:

- Cooling tower fans modulate via VFD to maintain the condenser water supply temperature (CWST) setpoint.
- Default CWST setpoint: 85 degrees F.
- **CWST Reset:** The CWST setpoint resets downward based on wet bulb temperature:
- CWST setpoint = Wet Bulb Temperature + Approach (minimum 7 degrees F approach)
- Minimum CWST setpoint: 65 degrees F (per chiller manufacturer minimum)
- Maximum CWST setpoint: 85 degrees F

Fan Staging (Multiple-Cell Tower):

- All fans start at minimum speed before staging up.
- Stage up: When any fan reaches 95% speed, the next fan starts at minimum speed.
- Stage down: When all fans are below 30% speed, one fan stops.

Basin Heater: Energizes when OAT drops below 40 degrees F and tower is idle, to prevent basin water from freezing.

9.4 Safety Limits

Safety	Trip Point	Reset
Low evaporator temperature	36 degrees F leaving CHW	Manual
High head pressure	300 psig (R-410A)	Manual
Low oil pressure	< 15 psig differential	Manual
High motor temperature	Per manufacturer limit	Auto (after 30 min cooldown)
Loss of CHW flow	Flow switch open for 10 sec	Auto
Anti-freeze protection	38 degrees F entering CHW	Manual

Safety	Trip Point	Reset
Low refrigerant	Pressure below manufacturer limit	Manual
Phase reversal	3-phase power reversed	Manual

9.5 Lead/Lag Rotation

For plants with multiple chillers, the lead/lag assignment shall rotate automatically based on runtime equalization. At the start of each calendar week (Monday at midnight), the chiller with the **lowest accumulated runtime hours** becomes the new lead machine.

For single-chiller plants, no lag machine is available. If the single chiller trips on a safety, the BMS shall generate a **Critical** alarm and all AHU economizers shall be enabled regardless of OAT to provide maximum free cooling.

10. Boiler Plant Sequence

10.1 Boiler Staging

Enable Condition for Boiler B-1:

The lead boiler (B-1) shall be enabled when **either** of the following conditions is true:

1. Any AHU hot water valve served by this plant is greater than **50% open** for a continuous period of **10 minutes**.
2. The outdoor air temperature (OAT) is below **55 degrees F**.

Disable Condition for Boiler B-1:

The lead boiler shall be disabled when **all** AHU hot water valves are less than **10% open** for 15 minutes **and** the OAT is above **60 degrees F**. The 5 degree F differential between enable and disable prevents short-cycling.

Staging for Multiple Boilers:

The lag boiler (B-2) shall be enabled when the lead boiler is firing above 80% capacity for 15 minutes and any AHU hot water valve remains above 50% open. B-2 shall be disabled when the combined plant load drops below 30% of total plant capacity for 15 minutes.

10.2 Hot Water Supply Temperature

The hot water supply temperature (HWST) setpoint defaults to **180 degrees F**. An outdoor air reset schedule adjusts the HWST setpoint:

Outdoor Air Temperature	HWST Setpoint
0 degrees F or below	180 degrees F
20 degrees F	165 degrees F
40 degrees F	150 degrees F

Outdoor Air Temperature	HWST Setpoint
60 degrees F or above	120 degrees F

The reset is linear between these points. For example, at an OAT of 30 degrees F, the HWST setpoint is 157.5 degrees F.

Condensing Boiler Optimization: For condensing boilers, the HWST setpoint should be maintained below the flue gas dewpoint (approximately 130 degrees F for natural gas) whenever possible to maximize condensing efficiency. The OAT reset schedule may be extended:

OAT	HWST Setpoint (Condensing)
0 degrees F	140 degrees F
20 degrees F	130 degrees F
40 degrees F	120 degrees F
60 degrees F	100 degrees F

10.3 Pump Control

The primary hot water pump (HWP-1) is interlocked with the lead boiler. The pump starts 30 seconds **before** the boiler fires to establish flow through the heat exchanger. The pump stops 5 minutes **after** the boiler is disabled to dissipate residual heat.

For systems with a secondary hot water loop, the secondary pump (HWP-2) operates on a VFD. The VFD speed is modulated via a PI loop to maintain the secondary loop differential pressure (DP) at setpoint. The DP sensor is located at the hydraulically most remote coil.

10.4 Safety Interlocks

Safety Device	Trip Condition	Response
High limit aquastat	HWST > 200 degrees F	Boiler OFF, manual reset
Low water cutoff	Water level below minimum	Boiler OFF, manual reset
Flame safeguard	No flame within ignition trial	Boiler lockout, manual reset
High flue gas temp	Flue temp > 450 degrees F	Boiler OFF, auto-reset after cooldown
Seismic switch	Seismic event detected	Boiler OFF, manual reset
Combustion air proving	Air damper not proven	Boiler will not fire
Gas pressure low	Gas pressure < 3" w.c.	Boiler will not fire
Gas pressure high	Gas pressure > 14" w.c.	Boiler will not fire

11. Pump Sequences

11.1 Primary Chilled Water Pump

The primary chilled water pump (CHWP-1) operates at **constant flow** and is interlocked with the lead chiller:

- CHWP-1 starts when CH-1 receives an enable command.
- CHWP-1 stops when CH-1 is disabled.
- A flow switch downstream of the pump shall confirm flow within 30 seconds of pump start.
- For multiple-chiller plants, each chiller has a dedicated primary pump.

11.2 Secondary Chilled Water Pump

The secondary chilled water pump (SCHWP-1) operates at **variable flow** via VFD:

- VFD speed modulates via PI loop to maintain secondary loop DP at setpoint.
- **Default DP setpoint:** 15 psig.
- **DP reset range:** 8 psig (minimum) to 15 psig (maximum).
- **Reset logic:** Trim-and-respond based on AHU CHW valve positions. If all valves below 80% open, trim DP down 0.5 psig. If any valve exceeds 95%, respond up 1.0 psig. Sampling interval: 2 minutes.
- **Minimum VFD speed:** 30%.
- **Staging:** Lag pump enabled when lead pump VFD reaches 95% speed for 10 minutes.

11.3 Primary Hot Water Pump

- HWP-1 starts 30 seconds before B-1 fires.
- HWP-1 stops 5 minutes after B-1 is disabled.
- Flow switch confirms flow within 30 seconds.

11.4 Secondary Hot Water Pump

- VFD speed modulates to maintain secondary loop DP at setpoint.
- **Default DP setpoint:** 12 psig.
- **DP reset range:** 5 psig (minimum) to 12 psig (maximum).
- **Minimum VFD speed:** 30%.

11.5 Condenser Water Pump

- CWP-1 is interlocked with CH-1.
- CWP-1 starts when the chiller receives an enable command.
- CWP-1 runs at constant flow (no VFD for condenser water in most applications).
- A flow switch confirms condenser water flow before the chiller is enabled.
- The condenser water isolation valve opens when the pump starts and closes when the pump stops.

12. Heat Recovery Systems

12.1 Enthalpy Wheel (Rotary Heat Exchanger)

Normal Operation:

- The enthalpy wheel rotates at 20-30 RPM when both the supply and exhaust fans are running.
- The wheel transfers both sensible and latent energy between the exhaust and supply air streams.
- Typical effectiveness: 70-80% total energy recovery.

Speed Control:

- Wheel speed modulates based on the supply air temperature deviation from setpoint.
- If the supply air is too warm after the wheel (in heating mode), the wheel speed increases.
- If the supply air is too cold after the wheel (in cooling mode), the wheel speed decreases or the bypass damper opens.

Frost Prevention:

- When OAT < 20 degrees F: Reduce wheel speed to limit frost formation.
- When exhaust air temperature leaving the wheel < 35 degrees F: Reduce wheel speed further.
- When exhaust air temperature leaving the wheel < 32 degrees F: Stop wheel, open bypass, alarm.
- Resume when exhaust leaving air temperature > 38 degrees F.

Cross-Contamination Prevention:

- A purge section shall be provided to prevent exhaust air carryover into the supply air stream.
- The purge sector shall be at least 5 degrees of arc.
- For applications requiring no cross-contamination (hospital ORs, lab exhaust), enthalpy wheels shall NOT be used — use plate exchangers or run-around loops instead.

12.2 Plate Heat Exchanger (Air-to-Air)

Operation:

- The plate HX is a static device with no moving parts.
- Supply and exhaust air streams pass through alternate channels separated by plates.
- Only sensible heat is transferred (no latent recovery unless plates are moisture-permeable).
- Typical effectiveness: 55-75% sensible.

Bypass Control:

- A bypass damper around the plate HX modulates when the supply air temperature after the HX exceeds the setpoint (during swing seasons when recovery is not needed).
- The bypass damper is modulated by the SAT PID loop.

Frost Prevention:

• When OAT < 10 degrees F: The exhaust bypass damper modulates to mix room-temperature air with the cold OA stream before entering the plate HX.

• A defrost cycle activates when the OA-side pressure drop across the plate exceeds 1.5x the clean DP (indicating frost buildup). The supply fan stops briefly while exhaust continues, warming the plates.

12.3 Run-Around Loop

Operation:

• A glycol/water solution circulates between a coil in the exhaust duct and a coil in the supply duct.

• A circulating pump moves the solution.

• Typical effectiveness: 45-65% sensible.

Pump Control:

• The run-around pump runs whenever both supply and exhaust fans are operating.

• A 3-way modulating valve bypasses some flow around the exhaust coil to control the supply air temperature after recovery.

Freeze Protection:

• The glycol concentration shall be sufficient for the coldest design OAT (typically 40% propylene glycol for -20 degrees F applications).

• A low-temperature sensor on the exhaust coil leaving fluid shuts down the pump if the fluid temperature drops below 20 degrees F.

13. Exhaust Fan Sequences

13.1 Restroom Exhaust Fan (EF-1)

• **Schedule:** Run during occupied hours only.

• **Interlock:** EF-1 is interlocked with the associated AHU supply fan. EF-1 shall not run unless the AHU supply fan is proven ON.

• **Airflow:** Constant volume per code-required exhaust rates (75 CFM per water closet, 50 CFM per urinal per IMC Table 403.3.1).

• **Alarm:** If no run status within 15 seconds of start command, generate "EF-1 Failure" alarm.

13.2 Server Room / IT Closet Exhaust Fan (EF-2)

• **Schedule:** Continuous operation, 24/7/365.

• **Interlock:** None (independent operation).

• **High temperature alarm:** Critical alarm at 85 degrees F. Second tier at 90 degrees F with email/SMS notification.

• **Backup power:** Connected to emergency power system.

• **Airflow:** 1 CFM per 30 BTU/hr of IT heat load.

13.3 General Exhaust Fan (EF-3)

- **Schedule:** Occupied hours per BMS schedule.
- **Interlock:** Interlocked with building supply air system.
- **Makeup air:** Transfer air dampers from adjacent spaces shall be open when EF-3 runs.
- **Building pressure:** Exhaust CFM shall not exceed 90% of supply CFM to maintain positive building pressurization.

14. Specialty Exhaust Systems

14.1 Kitchen Hood Exhaust

Type I Hood (Grease-Laden):

- Exhaust fan operates whenever cooking equipment is in use.
- Minimum exhaust rate: per IMC Table 507.2.1 based on hood type and cooking equipment.
- Makeup air unit (MAU) is interlocked with the exhaust fan.
- MAU delivers tempered air (55-65 degrees F) to prevent cold drafts.
- A fire suppression system interlock shuts down the exhaust fan upon activation (per NFPA 96).

Demand-Controlled Kitchen Ventilation (DCKV):

- Infrared temperature sensors and/or opacity sensors above the cooking surface detect cooking activity.
- When no cooking is detected, the exhaust fan speed reduces to 50% of design.
- When cooking activity is detected, the fan speed increases to 100%.
- The MAU modulates proportionally to maintain kitchen pressure balance.
- Energy savings: 30-50% reduction in exhaust fan energy.

14.2 Parking Garage Exhaust

CO/NO2 Monitoring System:

- Carbon monoxide (CO) sensors at parking level (1 sensor per 5,000 SF, minimum 2 per level).
- Nitrogen dioxide (NO2) sensors co-located with CO sensors.

Fan Control:

CO Level	NO2 Level	Fan Operation
< 25 ppm	< 1 ppm	Fans OFF (or minimum 0.05 CFM/SF for ASHRAE 62.1)
25-35 ppm	1-3 ppm	50% fan speed
> 35 ppm	> 3 ppm	100% fan speed
> 100 ppm	> 5 ppm	100% fan speed + Critical alarm

Time-Based Override:

- During peak hours (7-9 AM, 4-7 PM weekdays), fans run at 50% minimum regardless of sensor readings.
- During unoccupied hours, fans cycle on for 15 minutes every hour at minimum speed.

14.3 Stairwell Pressurization Fans

Fire Mode (Activated by fire alarm):

- Stairwell pressurization fans start immediately upon fire alarm activation.
- Target stairwell pressure: 0.05" w.c. to 0.10" w.c. above adjacent floor pressure (per NFPA 92).
- Maximum door-opening force: 30 lbf (per IBC 1010.1.3).
- Barometric relief dampers at the top of the stairwell prevent over-pressurization.
- Fans remain running until manually reset by the fire department.

Normal Mode:

- Fans are OFF during normal building operation.
- Monthly automatic test: Fans start for 5 minutes, verify run status, then stop.

14.4 Laboratory Fume Hood Exhaust

Variable Air Volume (VAV) Fume Hood:

- A face velocity controller maintains 100 FPM face velocity at the sash opening (per ANSI/AIHA Z9.5).
- As the sash is raised, the exhaust airflow increases proportionally.
- As the sash is lowered, the exhaust airflow decreases.
- Minimum exhaust: 25% of maximum (to maintain a safe minimum air change rate).

General Lab Exhaust:

- Minimum 6 ACH for lab spaces (ASHRAE 62.1 / ANSI Z9.5).
- Minimum 10 ACH when fume hoods are in use.
- Lab spaces maintained at negative pressure relative to corridors (-0.03" w.c.).

Supply Air Tracking:

- The lab supply air volume tracks the total lab exhaust volume to maintain the desired pressure relationship.
- Supply CFM = Total Exhaust CFM - Offset (typically 50-100 CFM to maintain negative pressure).

15. Radiant and Underfloor Systems

15.1 Radiant Ceiling Panels (Chilled and Heated)

Cooling Mode:

- Chilled water (typically 58-62 degrees F, higher than standard CHW to prevent condensation) circulates through ceiling-mounted radiant panels.
- A zone-level condensation sensor shuts down CHW flow if condensation is detected.
- The zone valve modulates based on zone temperature deviation from cooling setpoint.

Dewpoint Protection:

- The BMS continuously calculates the zone dewpoint from the space temperature and humidity sensors.
- CHW supply temperature must be maintained at least 2 degrees F above the zone dewpoint.
- If the CHW supply temperature approaches the dewpoint, the CHW valve closes and a "Condensation Risk" alarm is generated.

Heating Mode:

- Hot water (typically 90-110 degrees F, lower than standard HW for radiant comfort) circulates through the same or separate panels.
- Surface temperature limit: 85 degrees F maximum to prevent occupant discomfort.

15.2 Underfloor Air Distribution (UFAD)

Plenum Pressure Control:

- The supply fan delivers conditioned air to the underfloor plenum.
- A pressure sensor in the plenum maintains a setpoint of 0.05-0.10" w.c.
- The supply fan VFD modulates to maintain plenum pressure.

Floor Diffuser Control:

- Swirl diffusers in the floor allow occupant adjustment.
- Motorized floor diffusers (where installed) modulate based on zone temperature.
- Thermostatically controlled diffusers open when zone temperature rises above setpoint.

Supply Air Temperature (UFAD-Specific):

- UFAD systems use a higher supply air temperature than overhead systems: 63-65 degrees F (vs. 55 degrees F for overhead).
- This reduces the risk of draft complaints at floor level.
- The higher SAT also reduces dehumidification load on the cooling coil, saving energy.

16. Demand-Controlled Ventilation (DCV)

16.1 CO2-Based DCV

Single-Zone DCV:

- A CO2 sensor in the return air duct or representative zone location measures CO2 concentration.

• The OA damper minimum position modulates based on CO2:

CO2 Level	OA Damper Minimum
< 600 ppm	Minimum ventilation per 62.1 (design minimum)
600-800 ppm	Proportional between minimum and 100% OA
> 800 ppm	100% OA (if economizer available)
> 1000 ppm	Alarm: "High CO2 — Check Ventilation"

Multi-Zone DCV (per ASHRAE 62.1-2022 Section 6.2.7):

• Each zone has a CO2 sensor.

• The zone outdoor air setpoint (Vbz) resets based on zone CO2:

• At or below the outdoor CO2 baseline (typically 400 ppm), the zone OA requirement is the area-based component only (Ra * Az).

• At the zone CO2 setpoint (typically 1000 ppm above outdoor), the zone OA requirement is the full design Vbz = Rp *Pz + Ra* Az.

• Between baseline and setpoint: linear interpolation.

16.2 Occupancy Sensor-Based DCV

For zones with occupancy sensors (conference rooms, classrooms, lobbies):

• When the zone is unoccupied, the OA requirement drops to the area-based component only (Ra * Az).

• When the zone becomes occupied, the OA requirement increases to the full Vbz within 15 minutes.

• An occupancy count sensor (for large spaces) allows proportional reduction of the people-based component.

16.3 CO2 Sensor Calibration

• CO2 sensors shall be auto-calibrating (ABC logic) or manually calibrated every 5 years.

• Sensor accuracy: +/- 75 ppm per ASHRAE Standard 62.1.

• Sensors shall be mounted at 3-6 feet above floor level, away from diffusers, windows, and doors.

• Do not mount CO2 sensors near plants (photosynthesis absorbs CO2) or near coffee machines/kitchenettes (combustion releases CO2).

17. Optimal Start/Stop Algorithms

17.1 Optimal Start

The optimal start algorithm calculates the latest possible start time for the AHU to bring all zones to occupied setpoints before the scheduled occupancy time.

Inputs:

- Current zone temperatures (all zones served by this AHU)
- Outdoor air temperature
- Historical warm-up/cool-down rate (degrees F per minute)
- Scheduled occupancy time

Algorithm:

1. Calculate the required temperature change: Delta_T = T_occupied_setpoint - T_current.
2. Estimate warm-up rate based on the last 5 similar days: Rate = degrees F per minute.
3. Adjust rate for current OAT (colder OAT = slower warm-up).
4. Calculate required start time: Start = Occupancy_Time - (Delta_T / Rate) - Safety_Margin (15 min).
5. Earliest allowed start: 4 hours before scheduled occupancy.

Adaptive Learning:

- The algorithm tracks actual warm-up/cool-down performance daily.
- If the zone reached setpoint late, the algorithm starts earlier the next similar day.
- If the zone reached setpoint early, the algorithm starts later.
- "Similar days" are grouped by: OAT range, day of week, previous day occupied/unoccupied.

17.2 Optimal Stop

The optimal stop algorithm shuts down the AHU before the end of scheduled occupancy, allowing the building thermal mass to coast through the final period.

Logic:

- The AHU stops N minutes before the end of occupancy, where N is determined by how quickly the zone temperature drifts.
- If the zone temperature drifts more than 2 degrees F before the end of occupancy, reduce N by 5 minutes the next day.
- If the zone temperature stays within 1 degree F of setpoint until the end of occupancy, increase N by 5 minutes the next day.
- Maximum N: 60 minutes. Minimum N: 0 minutes (no early stop).

18. Demand Response and Load Shedding

18.1 Demand Response Event Levels

The BMS supports 3 levels of demand response (DR) events, triggered by utility signal, manual operator command, or automatic peak demand detection:

DR Level	Description	Actions
Level 1 (Moderate)	Reduce demand by 10-15%	Widen deadbands by 2 degrees F, reduce lighting 10%
Level 2 (Significant)	Reduce demand by 20-30%	Widen deadbands by 4 degrees F, reduce lighting 20%, stage off lag chillers
Level 3 (Emergency)	Reduce demand by 40%+	Maximum setpoint adjustments, non-critical loads OFF

18.2 Level 1 DR Sequence

1. Widen all zone cooling setpoints by 2 degrees F (e.g., 75 to 77 degrees F).
2. Lower all zone heating setpoints by 2 degrees F (e.g., 72 to 70 degrees F).
3. Reset SAT setpoint up by 2 degrees F (e.g., 55 to 57 degrees F).
4. Reset duct static pressure down by 0.2" w.c.
5. Reset CHWST up by 2 degrees F (e.g., 44 to 46 degrees F).
6. Reduce lobby and common area lighting by 10%.

18.3 Level 2 DR Sequence

All Level 1 actions plus:

1. Further widen zone deadbands to 4 degrees F total offset.
2. Stage off lag chillers and cooling towers.
3. Reduce supply fan maximum speed to 80%.
4. Shut off non-critical exhaust fans.
5. Reduce parking garage ventilation to minimum code requirement.
6. Pre-cool building (if advance notice is given) by lowering cooling setpoints 2 degrees F for 1 hour before the DR event.

18.4 Level 3 DR Sequence

All Level 1 and 2 actions plus:

1. Shut off all non-life-safety HVAC equipment.
2. Maintain only stairwell pressurization, smoke control, and server room cooling.
3. Close OA dampers to reduce ventilation to minimum.
4. Transfer critical loads to backup generator if available.

19. Fire Alarm HVAC Shutdown Sequences

19.1 General Fire Alarm Response (per NFPA 90A)

Upon activation of the building fire alarm system:

1. **All AHUs:** Supply and return fans STOP. OA dampers CLOSE. RA dampers CLOSE. Fire/smoke dampers close at duct penetrations through rated assemblies.
2. **All exhaust fans:** STOP (except stairwell pressurization and smoke control fans).
3. **All chilled water and hot water valves:** CLOSE.
4. **All VFDs:** STOP.
5. **Elevator recall:** Elevators return to designated floor.
6. **Kitchen hoods:** Exhaust fan STOP. Fire suppression system may activate independently.

Exception — Smoke Control Fans: Fans designated for smoke control (stairwell pressurization, smoke exhaust) shall START upon fire alarm activation, overriding the general shutdown.

19.2 Smoke Detector Response (Zone-Level)

When a duct-mounted smoke detector in a specific AHU activates:

1. That AHU supply and return fans STOP.
2. That AHU OA damper CLOSES.
3. Fire/smoke dampers in the associated ductwork CLOSE.
4. A "Smoke Detected — AHU-X" Critical alarm is sent to BMS.
5. The fire alarm panel is notified.
6. Other AHUs NOT affected continue normal operation (unless general alarm is activated).

19.3 Manual Reset Requirements

After a fire alarm event, the following require **manual reset** by authorized personnel:

- Duct smoke detectors
- Fire/smoke dampers (must be inspected before reopening)
- Stairwell pressurization fans (fire department control)
- Kitchen fire suppression interlocks
- Any equipment that tripped on safety during the event

The BMS shall display a "Fire Alarm Reset Checklist" screen showing all equipment requiring manual reset and their current status.

20. Smoke Control System Sequences

20.1 Stairwell Pressurization (per NFPA 92)

Activation:

- Upon fire alarm activation in any zone adjacent to the stairwell.
- The stairwell pressurization fan(s) start immediately.

Pressure Targets:

- Minimum pressure differential: 0.05" w.c. across each stairwell door.
- Maximum pressure differential: 0.10" w.c. (to keep door-opening force below 30 lbf).
- A DP sensor at the bottom, middle, and top of each stairwell monitors the differential.

Modulation:

- The fan VFD speed modulates to maintain the target DP.
- Barometric relief dampers at the top of the stairwell open if the pressure exceeds 0.10" w.c.
- If doors are opened (reducing DP), the fan speed increases automatically.

20.2 Smoke Exhaust (Atrium/Large Space)

Activation:

- Upon smoke detector activation in the atrium or designated smoke zone.
- Smoke exhaust fans START.
- Makeup air dampers OPEN to provide replacement air at low velocity (< 200 FPM at the smoke layer interface).

Exhaust Rate:

- Calculated per NFPA 92 smoke production equations based on fire size, ceiling height, and perimeter.
- Typical: 4-8 ACH for the smoke zone.

Tenability Criteria:

- Maintain the smoke layer at least 6 feet above the highest occupied floor.
- Visibility at the 6-foot level: minimum 30 feet.
- Temperature at the 6-foot level: maximum 140 degrees F.

21. Fault Detection and Diagnostics (FDD)

21.1 ASHRAE RP-1312 FDD Rules

The J∆S Engineering Suite includes built-in fault detection rules based on ASHRAE Research Project 1312. These rules run continuously in the BMS and flag anomalies:

AHU Faults:

Rule	Description	Condition
AHU-1	Heating and cooling simultaneously	HW valve > 10% AND CHW valve > 10%

Rule	Description	Condition
AHU-2	Economizer not operating when expected	OAT < 55 degrees F AND OA damper at minimum AND CHW valve > 50%
AHU-3	SAT too high	SAT > setpoint + 5 degrees F for 15 min
AHU-4	SAT too low	SAT < setpoint - 5 degrees F for 15 min
AHU-5	High duct SP with low fan speed	SP > setpoint AND fan speed < 50%
AHU-6	Stuck OA damper	OA damper command changes by > 20% but MAT does not change
AHU-7	Stuck CHW valve	CHW valve command > 90% but SAT not decreasing
AHU-8	Temperature sensor disagreement	MAT not between OAT and RAT (within tolerance)

VAV Faults:

Rule	Description	Condition
VAV-1	Zone overcooled	Zone temp < HSP - 3 degrees F during occupied
VAV-2	Zone overheated	Zone temp > CSP + 3 degrees F during occupied
VAV-3	Reheat on with cooling demand	Reheat valve > 10% AND damper > 80%
VAV-4	Simultaneous heating and cooling	Reheat valve > 10% AND zone requesting cooling
VAV-5	Stuck damper	Damper command changes but airflow does not
VAV-6	Leaking reheat valve	Discharge temp > SAT + 5 degrees F with reheat commanded OFF

Plant Faults:

Rule	Description	Condition
CH-1	Low delta-T syndrome	CHWR - CHWS < 6 degrees F with chiller at > 50% load
CH-2	Condenser fouling	Approach temp > 7 degrees F above design
B-1	Low boiler efficiency	Stack temp > 350 degrees F (non-condensing)
B-2	Short cycling	Boiler starts > 6 times per hour

21.2 FDD Dashboard

The J∆S Engineering Suite generates an FDD summary dashboard showing:

- Active faults (sorted by priority)

- Fault history (last 30 days)
- Energy impact estimate (BTU wasted per fault per day)
- Recommended corrective actions

22. Equipment Interlock Schedule

The following table defines the interlock relationships between all major equipment:

Primary Equipment	Interlocked Equipment	Enable Condition	Failure Mode
AHU-1 Supply Fan	CHW Valve (AHU-1)	Fan proven ON	Valve closes on fan failure
AHU-1 Supply Fan	HW Valve (AHU-1)	Fan proven ON	Valve closes on fan failure
AHU-1 Supply Fan	OA Damper (AHU-1)	Fan proven ON	Damper closes on fan failure
AHU-1 Supply Fan	EF-1 (Restroom)	Fan proven ON	EF-1 stops on AHU failure
AHU-1 Supply Fan	Return Fan (AHU-1)	Fan proven ON	Return fan stops
CHW Valve (any AHU)	CHWP-1	Any CHW valve > 5%	Pump runs if any valve calls
CHWP-1	CH-1	Flow switch proven	Chiller won't start without flow
CH-1	Condenser Fans/CT	Chiller running	Stop when chiller stops
HW Valve (any AHU)	HWP-1	Any HW valve > 5%	Pump runs if any valve calls
HWP-1	B-1	Flow switch proven	Boiler won't fire without flow
B-1	Combustion Air Damper	Boiler firing	Damper closes when boiler stops
Smoke Detector	AHU Supply Fan	Smoke detected	AHU stops, OA damper closes
Freeze Stat	AHU Supply Fan	Freeze tripped	AHU stops, HW valve opens 100%
Fire Alarm	All AHUs	Alarm active	All AHUs stop per NFPA 90A
Fire Alarm	Stairwell Press. Fans	Alarm active	Fans START
Kitchen Hood	MAU	Hood exhaust running	MAU starts with hood
Lab Exhaust	Lab Supply	Exhaust running	Supply tracks exhaust

Failure Cascade Example:

If CH-1 trips on a safety:

1. CH-1 stops immediately.
2. CHWP-1 continues to run for 5 minutes (pump-down period).
3. A "Chiller Failure" critical alarm is generated.
4. If a lag chiller exists, CH-2 is enabled after a 5-minute anti-short-cycle delay.
5. If no lag chiller exists, all AHU economizers are enabled.

6. All AHU SAT setpoints reset to 65 degrees F to reduce cooling demand.

23. BMS Points List

23.1 Air Handling Unit (per AHU)

Point Name	Type	Description	Units
SF_CMD	DO	Supply fan start/stop	On/Off
SF_STS	DI	Supply fan run status	On/Off
SF_SPD	AO	Supply fan VFD speed command	%
SF_SPD_FB	AI	Supply fan VFD speed feedback	%
RF_CMD	DO	Return fan start/stop	On/Off
RF_STS	DI	Return fan run status	On/Off
RF_SPD	AO	Return fan VFD speed command	%
SAT	AI	Supply air temperature	degrees F
RAT	AI	Return air temperature	degrees F
MAT	AI	Mixed air temperature	degrees F
OAT	AI	Outdoor air temperature	degrees F
OA_RH	AI	Outdoor air humidity	% RH
RA_RH	AI	Return air humidity	% RH
SA_SP	AI	Supply duct static pressure	" w.c.
FLT_DP	AI	Filter differential pressure	" w.c.
CHW_VLV	AO	Chilled water valve command	%
HW_VLV	AO	Hot water valve command	%
OA_DPR	AO	Outdoor air damper command	%
RA_DPR	AO	Return air damper command	%
SMOKE_SA	DI	Supply air smoke detector	Alarm/Normal
SMOKE_RA	DI	Return air smoke detector	Alarm/Normal
FREEZE	DI	Freeze stat status	Tripped/Normal
OA_FLOW	AI	Outdoor airflow	CFM
SA_CO2	AI	Return air CO2	ppm

Typical AHU point count: 14 AI, 5 AO, 6 DI, 2 DO = 27 points

23.2 VAV Terminal Unit (per box)

Point Name	Type	Description	Units
ZN_TEMP	AI	Zone temperature	degrees F
DISCH_TEMP	AI	Discharge air temperature	degrees F
AIRFLOW	AI	Zone airflow	CFM
DPR_CMD	AO	Damper position command	%
RH_VLV	AO	Reheat valve command	%
OCC_SEN	DI	Occupancy sensor	Occ/Unocc
ZN_CO2	AI	Zone CO2 (if DCV)	ppm

Typical VAV point count: 3-4 AI, 2 AO, 1 DI, 0 DO = 6-7 points

23.3 Chiller (per unit)

Point Name	Type	Description	Units
CH_CMD	DO	Chiller enable/disable	On/Off
CH_STS	DI	Chiller run status	On/Off
CH_ALM	DI	Chiller general alarm	Alarm/Normal
CHWST	AI	CHW supply temperature	degrees F
CHWRT	AI	CHW return temperature	degrees F
CWS_TEMP	AI	Condenser water supply temp	degrees F
CWR_TEMP	AI	Condenser water return temp	degrees F
CH_AMPS	AI	Compressor current	amps
CH_KW	AI	Chiller power	kW
CH_PCT	AI	Chiller load percentage	%

Typical chiller point count: 6-8 AI, 0 AO, 2 DI, 1 DO = 9-11 points

23.4 Boiler (per unit)

Point Name	Type	Description	Units
B_CMD	DO	Boiler enable/disable	On/Off
B_STS	DI	Boiler run status	On/Off
B_ALM	DI	Boiler general alarm	Alarm/Normal
HWST	AI	HW supply temperature	degrees F

Point Name	Type	Description	Units
HWRT	AI	HW return temperature	degrees F
B_FIRE	AI	Firing rate	%
FLUE_TEMP	AI	Flue gas temperature	degrees F

Typical boiler point count: 4 AI, 0 AO, 2 DI, 1 DO = 7 points

23.5 Pump (per unit)

Point Name	Type	Description	Units
PMP_CMD	DO	Pump start/stop	On/Off
PMP_STS	DI	Pump run status	On/Off
PMP_SPD	AO	VFD speed command	%
PMP_DP	AI	Differential pressure	psig
FLOW_SW	DI	Flow switch status	Flow/No Flow

Typical pump point count: 1 AI, 0-1 AO, 2 DI, 1 DO = 4-5 points

23.6 Cooling Tower (per cell)

Point Name	Type	Description	Units
CT_FAN_CMD	DO	Fan start/stop	On/Off
CT_FAN_STS	DI	Fan run status	On/Off
CT_FAN_SPD	AO	Fan VFD speed	%
CWS_TEMP	AI	Leaving water temperature	degrees F
CWR_TEMP	AI	Entering water temperature	degrees F
CT_BASIN	AI	Basin water temperature	degrees F
BASIN_HTR	DO	Basin heater command	On/Off
MAKEUP_VLV	DO	Makeup water valve	Open/Close

Typical cooling tower point count: 3 AI, 1 AO, 1 DI, 3 DO = 8 points

23.7 VRF System (per indoor unit)

Point Name	Type	Description	Units
ZN_TEMP	AI	Zone temperature	degrees F
ZN_SP	AO	Zone setpoint	degrees F

Point Name	Type	Description	Units
MODE	AO	Operating mode	Enum
FAN_SPD	AO	Fan speed	Enum
RUN_STS	DI	Unit run status	On/Off
FAULT	DI	Fault status	Alarm/Normal

Typical VRF indoor unit point count: 1 AI, 3 AO, 2 DI, 0 DO = 6 points

24. Network Architecture

24.1 BACnet Network Topology

A typical BACnet building automation network consists of three tiers:

Tier 1 — Enterprise / IT Network (BACnet/IP):

- Building automation servers, workstations, and web-based dashboards.
- Connected to the corporate IT network via a managed switch with VLAN isolation.
- BACnet/IP communication over TCP/UDP port 47808.

Tier 2 — Automation Level (BACnet/IP or BACnet MS/TP):

- DDC controllers for AHUs, chillers, boilers, and other major equipment.
- Each controller has a BACnet device ID and communicates via BACnet/IP (Ethernet) or BACnet MS/TP (RS-485).
- BACnet MS/TP networks: Maximum 32 devices per trunk, maximum 4,000 feet cable length, 76.8 kbaud.

Tier 3 — Field Level (BACnet MS/TP or Proprietary):

- VAV controllers, FCU controllers, and sensor/actuator modules.
- Connected via BACnet MS/TP daisy-chain bus to the Tier 2 controller.
- Each VAV controller manages 1-4 zones depending on manufacturer.

24.2 Integration Protocols

Protocol	Use Case	Notes
BACnet/IP	Primary BAS network	Standard for modern DDC systems
BACnet MS/TP	Field-level devices	RS-485, lower cost per point
Modbus TCP	Chillers, boilers, VFDs	Common for packaged equipment
Modbus RTU	Legacy field devices	RS-485, requires gateway
LON/LonTalk	Legacy BAS networks	Being replaced by BACnet
KNX	European lighting/HVAC	Rare in US commercial

Protocol	Use Case	Notes
MQTT	IoT sensors, cloud	Emerging for edge devices

24.3 System Integration Points

Fire Alarm System:

- Hardwired relay contacts from fire alarm panel to BAS.
- Dry contacts: general alarm (DO), zone alarm per floor (DO), smoke detector per AHU (DI).
- BACnet integration optional for monitoring only (not for life-safety control).

Lighting Control System:

- BACnet integration for occupancy status sharing.
- Lighting occupancy sensors can provide zone occupancy status to HVAC controllers for DCV and setback.

Access Control / Security:

- Badge reader data can indicate zone occupancy for HVAC scheduling.
- After-hours access triggers HVAC start for the accessed zone.

25. Cybersecurity for BAS

25.1 NIST Cybersecurity Framework for BAS

Building automation systems are increasingly connected to IT networks and the internet, making them targets for cyberattacks. The J∆S Engineering Suite recommends the following security measures based on NIST SP 800-82:

Network Segmentation:

- The BAS network shall be on a dedicated VLAN, isolated from the corporate IT network.
- A firewall with explicit allow rules shall separate the BAS VLAN from the IT VLAN.
- Only BACnet traffic (UDP 47808) and HTTPS (TCP 443) shall be allowed through the firewall.

Authentication:

- All BACnet devices shall require authentication for write operations (BACnet Secure Connect / BACnet/SC).
- Default passwords on all DDC controllers shall be changed before commissioning.
- Operator accounts shall use unique credentials with role-based access.

Monitoring:

- Network traffic monitoring shall detect anomalous BACnet commands (e.g., writes to safety-critical points from unknown devices).
- The BMS shall log all operator actions, configuration changes, and point overrides with timestamps and user IDs.

Physical Security:

- DDC controllers in mechanical rooms shall be in locked enclosures.
- Server rooms hosting BAS servers shall have badge access control.

26. Trending, Alarming, and Dashboards

26.1 Trending

All critical points shall be trended at the intervals specified below:

Point Category	Trend Interval	Retention
Zone temperatures	15 minutes	1 year
Supply/return air temperatures	5 minutes	1 year
Valve positions	5 minutes	6 months
Fan/pump speeds	5 minutes	6 months
Energy meters (kW, BTU)	15 minutes	2 years
Outdoor air conditions	15 minutes	2 years
CO2 levels	15 minutes	1 year
Alarms	Event-based	5 years

26.2 Alarm Priority Levels

Priority	Response Time	Examples
Critical (1)	Immediate (< 5 min)	Fire/smoke, freeze stat, chiller safety trip
High (2)	Within 1 hour	Equipment failure, high space temp, no flow
Medium (3)	Within 4 hours	Setpoint deviation, economizer fault, dirty filter
Low (4)	Next business day	Trending anomalies, sensor drift, minor faults
Information (5)	No response needed	Mode changes, schedule events, normal transitions

26.3 Energy Dashboard

The J∆S Engineering Suite generates a BMS energy dashboard specification including:

- **Real-time display:** Total building kW, cooling load (tons), heating load (MBH), total CFM.
- **Daily summary:** Cooling degree-day vs. actual kWh, heating degree-day vs. actual therms.
- **Monthly comparison:** Current month energy vs. same month last year.
- **Equipment efficiency:** Chiller kW/ton, boiler efficiency (%), fan power (W/CFM).

- **Weather normalization:** Energy use indexed to degree-days for fair comparison.

27. Commissioning Verification Procedures

27.1 Pre-Functional Testing

Before functional performance testing, verify:

Item	Verification
All sensors installed and connected	Read live values, compare to handheld instrument
All actuators stroke correctly	Command 0% to 100%, verify physical position
VFDs programmed correctly	Check acceleration/deceleration time, speed limits
Interlocks wired correctly	Trip each interlock, verify downstream response
Alarms configured correctly	Simulate each alarm condition, verify notification
Points named per specification	Compare BMS point list to design documents
Trends active	Verify trend data is recording at specified intervals
Schedules programmed	Verify occupancy schedules match design intent

27.2 Functional Performance Testing

Test each sequence under the following conditions:

AHU Tests:

1. **Occupied cooling:** Verify SAT control, economizer modulation, CHW valve response.
2. **Occupied heating:** Verify preheat valve, OA damper minimum, heating SAT setpoint.
3. **Economizer changeover:** Simulate OAT above and below changeover point.
4. **Unoccupied mode:** Verify fans stop, dampers close, valves close.
5. **Night setback:** Simulate high and low zone temperatures during unoccupied hours.
6. **Morning warm-up:** Verify optimal start, OA damper closed during warm-up.
7. **SAT reset:** Override zone demands to trigger reset up and down.
8. **Static pressure reset:** Override VAV damper positions to trigger reset.
9. **Freeze protection:** Simulate low MAT, verify freeze stat response.
10. **Smoke detection:** Simulate duct smoke detector, verify AHU shutdown.
11. **Fire alarm:** Activate fire alarm, verify complete HVAC shutdown response.

Chiller Plant Tests:

1. **Chiller staging:** Simulate AHU CHW valve demands to trigger chiller start/stop.

2. **CHWST control:** Verify chiller modulates to maintain setpoint.
3. **CHWST reset:** Override AHU valve positions to trigger reset.
4. **Lead/lag rotation:** Verify runtime-based lead/lag changeover.
5. **Safety shutdown:** Simulate low evaporator temp, verify chiller lockout.
6. **Condenser water control:** Verify cooling tower fan staging and CWST setpoint.

VAV Box Tests (Sample 20% of all boxes):

1. **Cooling mode:** Raise zone temp, verify damper opens.
2. **Heating mode:** Lower zone temp, verify reheat activates.
3. **Deadband:** Verify no heating or cooling in deadband range.
4. **Minimum airflow:** Verify damper does not close below minimum setpoint.
5. **Unoccupied mode:** Verify damper closes, reheat off.
6. **Occupancy override:** Simulate occupancy sensor, verify response.

27.3 Seasonal Testing

Some sequences cannot be fully tested during initial commissioning because the weather conditions are not present. These shall be tested during the opposite season:

- If commissioned in summer: Test heating mode, boiler staging, freeze protection, and morning warm-up during winter.
- If commissioned in winter: Test cooling mode, economizer operation, chiller staging, and DCV during summer.

The commissioning agent (CxA) shall return for seasonal testing within 10-12 months of initial commissioning.

28. Troubleshooting Guide

28.1 AHU Troubleshooting

Symptom	Possible Cause	Fix
SAT too high	CHW valve stuck closed	Override valve to 100%, check actuator
SAT too high	CHW pump not running	Check pump status, flow switch
SAT too high	Economizer stuck at minimum	Override OA damper to 100%, check linkage
SAT too low	HW preheat valve stuck open	Override valve to 0%, check actuator
SAT too low	Freeze stat tripped	Check for cold drafts, verify coil glycol
High duct SP	Dampers closing due to low demand	Verify SP reset is active
Low duct SP	Supply fan VFD at max, still low SP	Check for duct leaks, dirty filters
Economizer not engaging	High-limit lockout	Verify OAT sensor reads correctly

Symptom	Possible Cause	Fix
Economizer not engaging	OAT sensor reading high	Relocate sensor away from heat sources
Fans won't start	VFD fault	Check VFD display for fault code
Fans won't start	Smoke detector in alarm	Inspect duct detectors, reset if clear

28.2 VAV Box Troubleshooting

Symptom	Possible Cause	Fix
Zone too hot	Damper stuck at minimum	Override damper to 100%, check actuator
Zone too hot	Insufficient supply air	Check AHU duct SP, look for duct restrictions
Zone too cold	Reheat valve stuck open	Override valve to 0%, check actuator
Zone too cold	SAT too low	Check AHU SAT reset logic
Airflow reads zero	Airflow sensor dirty or disconnected	Clean or reconnect pressure tubes
Damper hunts	PID tuning too aggressive	Increase proportional band, increase integral time
Reheat hunting	PID tuning too aggressive	Increase proportional band

28.3 Chiller Plant Troubleshooting

Symptom	Possible Cause	Fix
CHWST too high	Chiller at full load, insufficient capacity	Stage on lag chiller
CHWST too high	Condenser water too hot	Check cooling tower, clean condenser
CHWST too low	Chiller short cycling	Increase staging delay timers
Low delta-T	3-way valves bypassing	Convert to 2-way, rebalance
Low delta-T	Oversized coils	Reduce CHW flow, verify valve authority
Chiller won't start	No flow proof	Check CHW pump, flow switch
Chiller trips on high head	Condenser fouling	Clean condenser tubes or fins
Chiller trips on low evap temp	Low CHW flow	Check pump, strainer, valve positions

28.4 Boiler Plant Troubleshooting

Symptom	Possible Cause	Fix
HWST too low	Boiler firing rate at maximum	Stage on lag boiler
HWST too high	Reset schedule not active	Verify OAT reset logic in BMS
Boiler short cycling	Oversized boiler, low load	Add buffer tank, widen deadband

Symptom	Possible Cause	Fix
Boiler won't fire	No flow proof	Check HW pump, flow switch
Boiler won't fire	Combustion air damper not proven	Check damper linkage, end switch
Boiler lockout	Flame failure	Check gas pressure, ignitor, flame sensor
High stack temperature	Heat exchanger fouling	Clean heat exchanger tubes

29. Abbreviations

Abbreviation	Definition
ACH	Air Changes per Hour
AHU	Air Handling Unit
AI	Analog Input (BACnet)
AO	Analog Output (BACnet)
BAS	Building Automation System
BMS	Building Management System
BSB	Branch Selector Box (VRF)
BTU	British Thermal Unit
CFM	Cubic Feet per Minute
CH	Chiller
CHW	Chilled Water
CHWP	Chilled Water Pump
CHWRT	Chilled Water Return Temperature
CHWST	Chilled Water Supply Temperature
CO	Carbon Monoxide
CO2	Carbon Dioxide
COP	Coefficient of Performance
CSP	Cooling Setpoint
CW	Condenser Water
CWST	Condenser Water Supply Temperature
CxA	Commissioning Agent
DCV	Demand-Controlled Ventilation
DDC	Direct Digital Control
DI	Digital Input (BACnet)

Abbreviation	Definition
DO	Digital Output (BACnet)
DOAS	Dedicated Outdoor Air System
DP	Differential Pressure
DR	Demand Response
DX	Direct Expansion
EEV	Electronic Expansion Valve
EF	Exhaust Fan
FDD	Fault Detection and Diagnostics
FPM	Feet Per Minute
GPM	Gallons Per Minute
HSP	Heating Setpoint
HW	Hot Water
HWP	Hot Water Pump
HWRT	Hot Water Return Temperature
HWST	Hot Water Supply Temperature
IBC	International Building Code
IMC	International Mechanical Code
MAT	Mixed Air Temperature
MAU	Makeup Air Unit
MBH	Thousand BTU per Hour
MERV	Minimum Efficiency Reporting Value
MQTT	Message Queuing Telemetry Transport
MS/TP	Master-Slave/Token-Passing
NO2	Nitrogen Dioxide
OA	Outdoor Air
OAT	Outdoor Air Temperature
PID	Proportional-Integral-Derivative
RA	Return Air
RAT	Return Air Temperature
RTU	Rooftop Unit
SA	Supply Air
SAT	Supply Air Temperature

Abbreviation	Definition
SCHWP	Secondary Chilled Water Pump
SHWP	Secondary Hot Water Pump
SOO	Sequence of Operations
SP	Static Pressure
UFAD	Underfloor Air Distribution
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VLAN	Virtual Local Area Network
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume

This guide was generated by the J∆S Engineering Suite v1.2. All sequences conform to ASHRAE Guideline 36-2021, ASHRAE Standard 90.1-2022, ASHRAE Standard 62.1-2022, NFPA 90A, and NFPA 92. Consult the project mechanical engineer for project-specific modifications.