PE

BuilderCE

PROFESSIONAL ENGINEERING CONTINUING EDUCATION

HVAC Systems

Design Review, Constructability, Controls & Commissioning

Self-Paced Course Study Guide



Contextual mechanical-room photograph. Equipment and piping illustrate system context; the photograph does not establish design adequacy or compliance.

COURSE	CREDIT / CATEGORY	INSTRUCTOR
ENG-017	4 CEH / PDH · Area of Practice · Mechanical (HVAC / Building Mechanical Systems)	William Chase Roberts, P.E.

Superior Learning, LLC d/b/a BuilderCE

HVAC SYSTEMS

4 CEH

MECHANICAL

AREA OF PRACTICE

Course overview

HVAC systems rarely fail because one equation was solved incorrectly in isolation. More often, performance problems arise at the interfaces between design intent, equipment selection, architectural and structural constraints, electrical service, controls, installation, testing, balancing, commissioning, and actual building operation. An air-handling unit may be properly sized but impossible to replace. A variable-air-volume system may be theoretically efficient but unstable because sensors are poorly located or the sequence of operation does not match the physical system. A chilled-water pump may meet the scheduled duty point while the differential-pressure control strategy forces control valves to hunt at part load. A commissioning test may identify a failed mode transition that was never described clearly enough in the design documents for the controls contractor to program it correctly.

For the practicing mechanical engineer, these failures are not separate topics. They are different manifestations of the same professional problem: converting design intent into a coordinated, constructible, controllable, verifiable system.

This course develops a design-to-operation review method for HVAC and building mechanical systems. The emphasis is not introductory HVAC theory. The learner is assumed to understand core mechanical engineering concepts and to be able to read construction documents, equipment schedules, submittals, control diagrams, and sequences of operation. The course instead asks the questions that become critical when an engineer must review, coordinate, troubleshoot, or accept a real project.

The six modules move through the project in the same general direction that technical risk moves. Module 1 begins with the design basis and asks whether the documents describe a coherent system. Module 2 moves into constructability and asks whether the system can actually be installed, accessed, maintained, replaced, drained, supported, insulated, and phased. Module 3 examines distribution performance and the transition from drawings to field conditions. Module 4 treats controls and sequences of operation as engineering documents rather than programming afterthoughts. Module 5 uses commissioning and functional performance testing to verify whether the installed system behaves as intended. Module 6 integrates the earlier material through applied HVAC cases.

The course is intentionally broad enough to serve as a Mechanical Area-of-Practice course for engineers whose practice includes HVAC and building mechanical systems, but it is not intended to replace specialist courses in load calculations, psychrometrics, ventilation design, chilled-water plant design, refrigeration safety, testing and balancing, energy modeling, or Florida code compliance. Those topics are referenced only to the extent necessary to support design review, constructability, controls, and commissioning decisions.

Using the technical references

The course uses established HVAC design, constructability, control and commissioning principles. Reference editions include ASHRAE 55-2023, 62.1-2025, 90.1-2025, Guideline 36-2024, Standard 202-2024 and Guideline 1.1-2025. A published consensus standard is not automatically the legally adopted edition. Apply the governing jurisdiction, contract and published addenda/errata to the actual project. Florida examples use the currently effective 8th Edition (2023) Florida Building Code; the 9th Edition (2026) is scheduled to take effect December 31, 2026.

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Learning objectives

Upon successful completion of this course, the learner should be able to:

1. Develop and apply a structured HVAC design-review process that checks design criteria, load assumptions, system selection, equipment schedules, distribution concepts, sequences, maintainability, and coordination requirements.
2. Identify constructability and coordination risks involving equipment access, clearances, shafts, ceiling spaces, routing, supports, service zones, drainage, vibration isolation, acoustics, phasing, temporary conditions, and trade interfaces.
3. Evaluate airside and hydronic system documentation for internal consistency, practical installability, balancing capability, controllability, maintainability, and alignment among drawings, schedules, specifications, and control sequences.
4. Review HVAC controls and sequences of operation for sensor and actuator logic, safeties, setpoints, resets, economizer or optimization strategies where applicable, alarms, overrides, trend requirements, failure modes, and interfaces with other systems.
5. Explain how commissioning activities—design review, submittal review, prefunctional verification, functional-performance testing, deficiency management, seasonal or deferred testing, training, and turnover—provide evidence that installed systems can perform as intended.
6. Apply an integrated design-review and commissioning workflow to realistic HVAC case scenarios and identify where engineering clarification, redesign, field correction, controls revision, retesting, or owner decision is required.

Study plan and navigation

MODULE	MINUTES	FOCUS
1	35	Design basis, design review and system intent
2	45	Equipment, airside and hydronic constructability
3	40	Distribution performance and field reconciliation
4	50	Controls, sequences and BAS integration
5	40	Commissioning, functional performance and turnover
6	30	Integrated cases and engineering decision practice

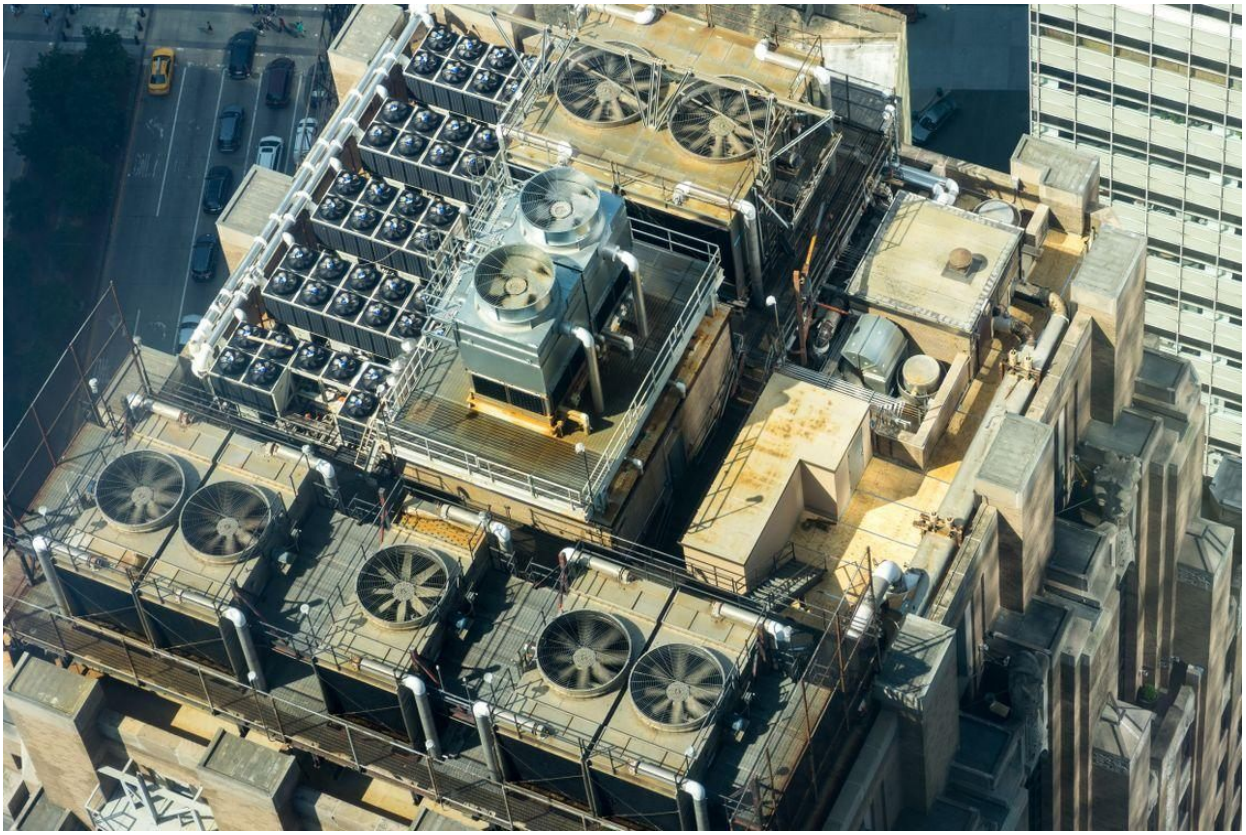
Planned instructional time: 240 minutes, exclusive of the final examination. Individual study time may vary.

How to complete this course

Read all modules in this course. No separate module acknowledgement is required. When you have finished reading, select Continue at the bottom of the BuilderCE lesson page to begin the 10-question final examination. If you are reading the PDF, return to that webpage first. A score of at least 70% is required to pass.

Command, response, diagnosis and retest · Principal sources

HVAC Design BASis, Design Review & System Intent



Contextual photograph: Rooftop mechanical equipment provides context for system layout, service and replacement access.

1.1 DESIGN REVIEW IS A SYSTEMS CHECK, NOT A REDLINE EXERCISE

DESIGN-TO-OPERATION STAGE	REQUIRED TRACEABILITY
Owner requirements	What the building must accomplish.
Basis of design	Why the system is configured this way.
Design documents	What must be built and controlled.
Submittals / installation	What is selected and installed.
Controls / TAB	How the system is installed, balanced and programmed.
Functional testing	What the installed system proves under test.
Turnover / operations	How accepted performance is sustained.

A useful HVAC design review is not a search for drafting errors. It is an attempt to determine whether the documents describe a system that can perform the intended function under the expected range of operating conditions.

That distinction matters because perfectly coordinated drawings can still describe a poor system, and excellent engineering intent can still be undermined by incomplete documents. The reviewer therefore needs two simultaneous perspectives. The first is analytical: do the loads, capacities, flows, pressures, temperatures, ventilation quantities, equipment characteristics, and control concepts make engineering sense? The second is integrative: do the plans, schedules, specifications, details, diagrams, controls, electrical requirements, structural interfaces, architectural constraints, and commissioning requirements describe the same system?

A design review should be structured enough that important questions are not skipped merely because the drawings look familiar. Familiarity is a risk. Experienced engineers can become efficient at recognizing common layouts, but that efficiency can turn into pattern matching. A system that looks like dozens of prior systems may still contain one critical difference: a much lower load profile, a highly variable occupancy pattern, a humidity-sensitive process, a replacement constraint, a smoke-control interface, a restrictive electrical service, a phased renovation, or a control dependency that changes how the entire design should operate.

The reviewer's job is therefore not to confirm that the design resembles a known solution. The job is to test whether the proposed solution is coherent for this project.

1.2 START WITH THE OWNER AND OPERATING PROBLEM

Design review should begin before the equipment schedule. The first question is: what problem is the HVAC system expected to solve?

That sounds obvious, but project documents often contain several versions of the answer. The owner may describe comfort, resilience, low first cost, low operating cost, rapid construction, maintainability, indoor-air-quality performance, redundancy, humidity control, acoustics, or future flexibility as priorities. The basis of design may emphasize only some of those priorities. The final construction documents may emphasize whatever survived budget revisions and coordination. The controls sequence may reflect a later interpretation by the design engineer or controls contractor. By commissioning, the project team may discover that no single document states the final operating intent clearly.

A strong reviewer traces the operating problem through the documents.

For example, consider a medical office building where the owner's priority is rapid recovery after unoccupied periods, tight temperature control during occupied hours, and simple maintenance by a small facility staff. A design may technically satisfy peak loads while failing the operating problem if it uses complex sequences that the staff cannot maintain, if morning warm-up cannot recover fast enough, or if equipment access requires service procedures that exceed the owner's capabilities.

Similarly, a speculative office building may require flexibility for unknown tenant layouts. A highly optimized system that depends on fixed occupancy and zoning assumptions may be efficient at design conditions yet create expensive rework as tenant spaces change.

The reviewer should identify the hierarchy of project drivers early. Typical drivers include: thermal comfort; ventilation and indoor-air-quality requirements; temperature and humidity control; process or equipment loads; pressurization relationships; energy efficiency; resilience and redundancy; maintainability; service and replacement access; operating simplicity; and acoustics and vibration. Additional considerations include construction phasing; future expansion; capital cost; lifecycle cost; available utilities; electrical-service limitations; building-envelope behavior; architectural constraints; structural capacity; and owner staffing and controls capability.

These drivers are not always compatible. Design is often the management of competing constraints rather than optimization of a single metric.

1.3 ESTABLISH THE DESIGN BASIS BEFORE REVIEWING COMPONENTS

A design basis should allow a technically competent reviewer to answer, at minimum:

- What outdoor and indoor design conditions were used?
- What occupancy schedules and internal loads were assumed?
- What ventilation basis was used?

- What envelope and infiltration assumptions influence the load?
- What diversity assumptions were applied?
- What operating schedules are expected?
- What temperature and humidity targets are important?
- What zoning philosophy is being used?
- What systems were considered and why was the selected system chosen?
- What redundancy or standby philosophy applies?
- What future capacity, if any, is included?
- What energy or sustainability objectives control the design?
- What constraints limit equipment location, distribution, or utilities?
- What critical sequences define part-load operation?

The reviewer does not need a narrative answer to every question if the information is clearly contained in the documents. But the information must exist somewhere and be internally consistent.

One of the most common review failures is allowing scheduled equipment capacity to substitute for a documented design basis. A 50-ton unit on a schedule does not prove that 50 tons is appropriate. It only proves that someone selected or scheduled a 50-ton unit.

Likewise, an outside-air quantity on a schedule does not explain whether it is based on occupancy, area, exhaust makeup, pressurization, a special occupancy requirement, or a control minimum. Without that context, the reviewer cannot evaluate whether a later controls sequence that resets outside air is appropriate.

1.4 DESIGN LOADS: REVIEW THE ASSUMPTIONS, NOT JUST THE TOTAL

This course is not a load-calculation course, but design review requires enough load awareness to identify when the assumptions behind equipment selection are questionable. Peak load matters, but so does the shape of the load.

A building can have the same nominal peak cooling load under several very different conditions: high solar load with moderate internal load; high ventilation load; high latent load; high plug/process load; high occupancy density; unusual envelope exposure; short-duration peak conditions; and long steady operating periods.

Those differences affect system selection, dehumidification, ventilation control, terminal behavior, reheat, part-load efficiency, and controls. The reviewer should therefore look beyond the final total and ask how the load was built.

Important questions include:

1. Are the occupancy densities realistic for the actual use? 2. Are operating schedules realistic, or were default schedules used without project-specific review? 3. Are process and equipment loads documented? 4. Are envelope assumptions consistent with the architectural documents? 5. Is infiltration treated consistently with building pressurization and entry conditions? 6. Are ventilation quantities reflected in the load model and the equipment selection? 7. Is latent load meaningful for the occupancy, climate, or process? 8. Are diversity factors appropriate? 9. Are future loads included, and if so, are they documented?

10. Does equipment selection reflect realistic part-load operation rather than only the peak point?

A reviewer should be suspicious of unexplained safety factors layered on top of conservative assumptions. Oversizing can appear safe but create new problems: poor part-load efficiency, cycling, inadequate dehumidification, unstable control, excessive airflow, noise, and higher first cost.

At the same time, the reviewer should not treat every capacity margin as an error. Equipment selection must account for catalog performance, fouling, altitude where applicable, coil conditions, fan heat, ventilation load, defrost or low-ambient behavior where relevant, and practical operating ranges. The objective is not minimum capacity. The objective is defensible capacity.

1.5 VENTILATION IS A DESIGN INPUT AND A CONTROL REQUIREMENT

Ventilation cannot be reviewed only as a static airflow on an equipment schedule.

Modern ventilation requirements frequently interact with occupancy, zones, system ventilation efficiency, air distribution, demand-controlled ventilation, filtration, controls, exhaust, pressure relationships, and outdoor-air measurement. ASHRAE Standard 62.1-2025 continues to establish minimum ventilation and other measures for acceptable indoor air quality in nonresidential buildings and now includes updated control-related requirements, including demand-control-ventilation sequence provisions.

For design review, the practical issue is traceability.

If a system has a minimum outdoor-air requirement, the reviewer should be able to identify: the source of the minimum; the condition at which it applies; the zone or system quantities that produce it; whether exhaust or pressure relationships create a larger requirement; how outdoor air is measured or inferred; how the system maintains the required minimum across operating modes; how variable-air-volume turndown affects distribution; what happens during unoccupied, warm-up, cooldown, smoke, purge, economizer, or other special modes; what sensors and control points are needed to execute the intended sequence; and how commissioning will verify that the minimum is actually delivered.

This is a recurring theme in the course: a design criterion is incomplete until the physical system and control sequence can deliver and verify it.

A common failure mode occurs when the ventilation calculation is correct but the control implementation is not. For example, a variable-air-volume air handler may be scheduled with the correct design outdoor airflow, but at low supply airflow the outside-air damper position that worked at design flow may no longer represent the same outdoor-air quantity. If the sequence relies only on damper position, the system may drift from the intended ventilation rate.

The exact solution depends on the system, applicable standard, measurement strategy, and project requirements. The review point is that the engineer should not assume a scheduled value will remain true under all modes without a control strategy that makes it true.

1.6 THERMAL COMFORT IS MORE THAN SPACE TEMPERATURE

ASHRAE Standard 55-2023 describes thermal comfort in terms of interacting environmental and personal factors. For design review, the key lesson is that a thermostat reading alone does not prove acceptable thermal conditions.

A space can meet a temperature setpoint and still generate complaints because of: radiant-temperature effects; excessive or insufficient air movement; vertical temperature gradients; drafts; solar asymmetry; local hot or cold surfaces; humidity conditions; clothing/activity differences; stratification; diffuser performance; poor zoning; and sensor location.

The reviewer should therefore examine whether the zoning, diffuser layout, perimeter strategy, return-air path, sensor placement, and system response are compatible with the occupied environment.

This is particularly important in spaces with large glazed areas, high ceilings, unusual occupancy, varying exposures, high internal loads, or significant air movement.

A controls sequence that maintains a room sensor at 74°F is only as good as the assumption that the sensor represents the occupied environment. If the sensor is located in a return plenum, on a sun-exposed wall, near a door, near equipment, or in a zone that combines incompatible exposures, excellent control of the sensor value may still produce poor comfort.

1.7 SYSTEM SELECTION SHOULD BE REVIEWED AGAINST PART-LOAD REALITY

HVAC systems spend much of their operating life away from peak design conditions. Design review should therefore ask how the selected system behaves across the expected operating range.

For an airside system, questions may include:

- How low can supply airflow realistically go?
- What happens to ventilation at low flow?

- How will static pressure be controlled?
- Can terminal units control effectively at minimum flow?
- How will heating and cooling transitions occur?
- Are fan selections stable across the expected range?
- Is heat recovery effective under relevant conditions?
- What happens when only a small fraction of zones call for cooling?

For a hydronic system:

- How does pump operation change as valves close?
- Where is differential pressure sensed?
- Are control valves selected for meaningful authority?
- Is minimum equipment flow required?
- What is the low-load plant strategy?
- How do lead/lag and staging decisions occur?
- What happens during pump or chiller failure?
- Can the system maintain controllability without excessive bypassing?

For heat-pump systems:

- What are the low-ambient or high-ambient limitations?
- How are defrost or supplemental heat handled?
- Are refrigerant-piping and branch-control limitations reflected?
- How does simultaneous heating and cooling, if available, affect control?
- What is the response to loss of a branch controller or outdoor unit?

The exact questions vary, but the method is consistent: do not stop at the design point.

1.8 EQUIPMENT SCHEDULES ARE ENGINEERING CONTRACTS WITH THE REST OF THE DOCUMENTS

An equipment schedule often becomes the most heavily referenced mechanical document during procurement. That makes schedule quality disproportionately important. A useful schedule should communicate enough information to establish the expected duty without attempting to reproduce an entire manufacturer catalog.

Depending on equipment type, important information can include: airflow or water flow; entering and leaving conditions; total, sensible, or latent capacity where relevant; heating capacity; pressure drop; fan external static pressure; fan power or motor characteristics; pump head; and efficiency or performance metric. Additional considerations include filtration; coil rows or performance criteria where needed; electrical characteristics; sound criteria; minimum/maximum operating conditions; redundancy; controls interfaces; accessories; and service requirements.

The reviewer should cross-check scheduled values against the plans and specifications. Common inconsistencies include: ductwork sized for a different airflow than the schedule; pump head that does not align with the calculated system resistance; coil pressure drops that are inconsistent between schedule and submittal; fan external static pressure that omits filters, coils, devices, or future losses; electrical voltage that differs from electrical documents; condensate requirements not reflected in plumbing coordination; equipment weights that differ from structural assumptions; access requirements that are not shown in plan; filtration levels that increase pressure drop beyond the fan selection basis; and control accessories required by the sequence but absent from the schedule.

A schedule should be read as part of a system, not as an isolated table.

1.9 REDUNDANCY: DEFINE WHAT FAILURE THE DESIGN IS TRYING TO SURVIVE

The word redundant is frequently used without enough precision.

Redundancy can mean: spare capacity; standby equipment; multiple smaller units; N+1 configuration; dual electrical feeds; bypass capability; alternate control paths; manual fallback; and distributed systems that limit the impact of one failure.

But redundancy should be tied to a failure scenario.

If a chilled-water plant has three chillers, is it redundant at design peak, average load, or only shoulder conditions? If two pumps are described as lead/lag, can either pump carry the full required load? Does a standby air handler actually have ductwork and controls that allow it to serve the failed unit's area? If the building automation system (BAS) network fails, does local equipment continue safely? If a primary sensor fails, is there a fallback value or does the system disable?

A reviewer should identify the single failures that matter and ask whether the system response is deliberate.

Redundancy that exists only on a schedule can disappear at the system level because of common dependencies. Two chillers may share one cooling tower cell, one electrical switchboard, one common header with a critical valve, or one controls panel. Two air handlers may share one outside-air unit. Multiple pumps may share one differential-pressure sensor. The review should therefore look for common-mode failure.

1.10 MAINTAINABILITY IS A DESIGN PERFORMANCE REQUIREMENT

Maintainability is often treated as a construction detail. It is an engineering performance issue. A component that cannot be accessed, cleaned, serviced, calibrated, removed, or replaced is not fully functional over its expected life.

Design review should identify: filter-removal paths; coil-cleaning access; fan/motor removal; tube-pull or heat-exchanger service zones; valve and strainer access; damper access; and sensor access. Additional considerations include actuator access; electrical disconnect clearance; control-panel access; roof access; drainage and washdown provisions; and rigging/replacement paths.

Maintainability should also consider the owner's actual maintenance model. A sophisticated central plant operated by trained stationary engineers can support a different level of complexity than a small commercial building maintained by a general facility technician.

Complexity is not inherently bad, but undocumented complexity becomes operational risk.

1.11 READ THE SPECIFICATIONS FOR DECISIONS THAT ARE NOT ON THE DRAWINGS

Mechanical drawings are not the entire design.

Specifications may control: materials; pressure classes; insulation; leakage testing; equipment quality; sound requirements; controls responsibilities; submittal content; and startup requirements. Additional considerations include testing, adjusting, and balancing (TAB); commissioning; warranties; training; operations and maintenance (O&M) documentation; spare parts; identification; testing requirements; and qualifications.

A reviewer should identify whether critical requirements exist only in specifications and whether those requirements are coordinated with the plans.

For example, a sequence may require airflow measurement, but the specifications may not require an airflow station or a control point capable of producing the required information. A commissioning section may require functional testing of modes that are not described in the controls narrative. A TAB specification may require measurements at locations that lack balancing devices.

These gaps are often discovered late because each document appears reasonable by itself.

1.12 THE SEQUENCE OF OPERATION BELONGS IN DESIGN REVIEW FROM THE BEGINNING

Controls are addressed in detail later, but the sequence of operation must be considered during initial design review because it reveals whether the mechanical design has a coherent operating concept.

A good reviewer should be able to answer:

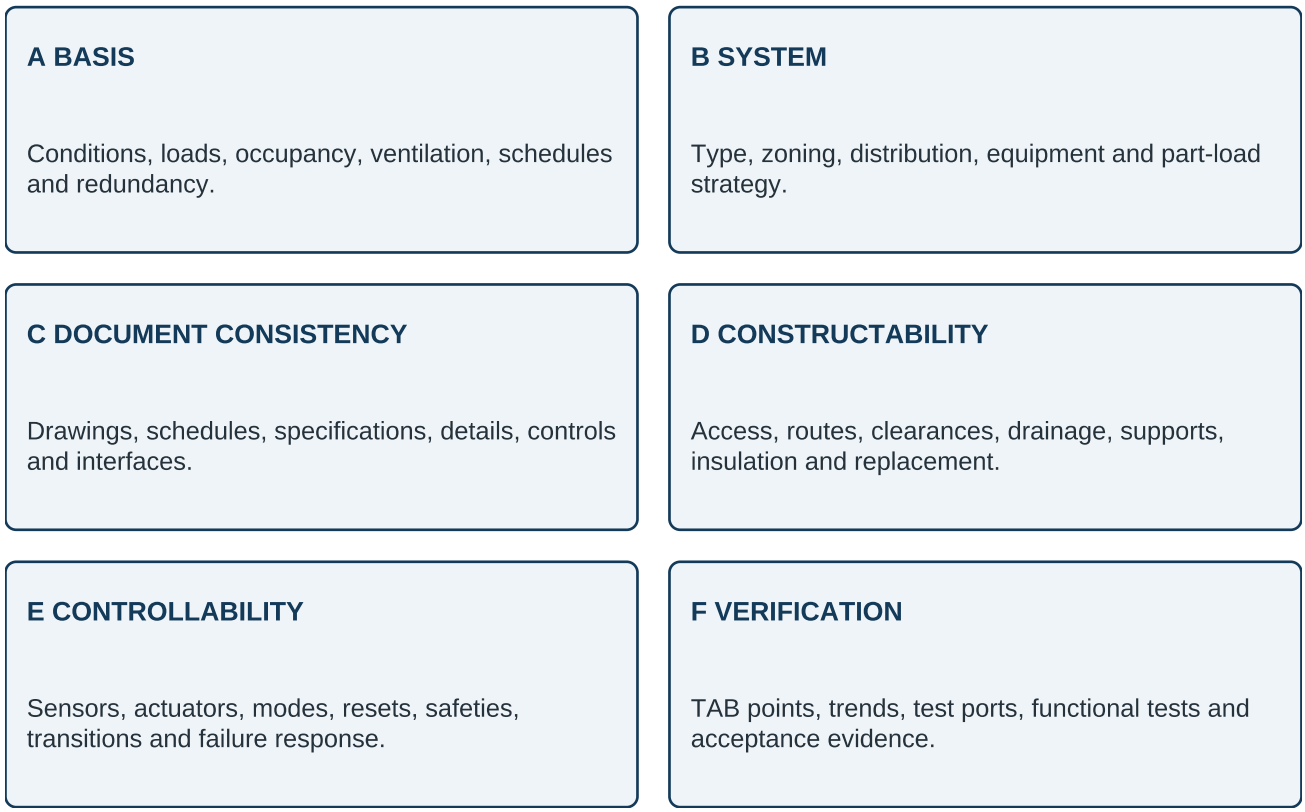
- What starts the system?
- What stops it?
- What determines occupied versus unoccupied operation?
- How are supply-air temperature and pressure controlled?

- How are pumps enabled and staged?
- What are the minimum and maximum terminal flows?
- How is ventilation maintained?
- What happens when outside conditions permit economizer operation?
- What happens when outside conditions are extreme?
- How do heating and cooling transitions occur?
- What happens when a sensor fails?
- What happens when equipment proves fail?
- What safeties override normal operation?
- Which alarms require operator response?
- What is trended?
- How does the system recover after power loss?
- What manual overrides are allowed?
- How are overrides cleared?

If those questions cannot be answered until the controls contractor develops submittals, the engineer has delegated too much of the system operating concept.

Guideline 36-2024 is useful context because it demonstrates that sequences can be engineered systematically to improve performance, control stability, and fault detection. A project does not need to adopt a particular guideline wholesale for the lesson to apply: sequences are design documents.

1.13 USE A DESIGN-REVIEW MATRIX



A structured HVAC evaluation checks basis, system, document consistency, constructability, controllability and verification without replacing engineering judgment.

A practical review matrix helps avoid omission. One useful structure is:

A. BASIS

- project requirements;
- design conditions;

- occupancy;
- loads;
- ventilation;
- redundancy;
- operating schedule.

B. SYSTEM

- system type;
- zoning;
- distribution concept;
- equipment;
- part-load strategy;
- energy strategy.

C. DOCUMENT CONSISTENCY

- plans;
- schedules;
- specifications;
- details;
- diagrams;
- controls;
- electrical;
- structural;
- architectural.

D. CONSTRUCTABILITY

- access;
- routing;
- clearances;
- supports;
- drainage;
- insulation;
- replacement;
- phasing.

E. CONTROLLABILITY

- sensors;
- actuators;
- valves/dampers;
- reset strategies;
- safeties;
- transitions;
- failure modes.

F. VERIFICATION

- test ports;
- balancing devices;
- BAS trends;
- commissioning points;
- functional-test capability;
- documentation.

The matrix is not a substitute for judgment. It is a way to make judgment repeatable.

1.14 CLASSIFY REVIEW COMMENTS BY CONSEQUENCE

Not every review comment deserves the same weight.

A reviewer can improve project communication by distinguishing among: life-safety or regulatory concern; performance risk; constructability risk; controls/commissioning risk; maintenance risk; coordination conflict; documentation inconsistency; value-engineering opportunity; clarification; and preference.

This helps the project team focus on consequential issues rather than treating a minor drafting comment and a system-performance defect as equivalent.

A good comment should state:

1. What was observed. 2. Why it matters. 3. What information or action is needed. 4. Whether the comment is a requirement, risk, question, or recommendation.

For example:

Weak comment:

“Check air-handling unit (AHU) access.”

Stronger comment:

“AHU-3 is shown approximately 18 inches from the wall on the filter-access side. The scheduled unit requires full-side filter removal and coil service access. Confirm manufacturer service-clearance requirements and revise the room layout or equipment orientation so routine filter replacement and coil service can be performed without dismantling adjacent piping.”

The stronger comment identifies the observed condition, consequence, and required verification.

1.15 DESIGN REVIEW SHOULD CLOSE THE LOOP

A review is not complete because comments were issued.

The reviewer should track disposition: accepted and revised; clarified with no change; rejected with technical rationale; deferred; transferred to another discipline; owner decision required; and field verification required.

Unresolved comments should remain visible until the project team consciously accepts the residual risk or provides a technical resolution.

This discipline becomes even more important when reviews occur across multiple phases. A design-development comment may be “resolved” by a note that the issue will be addressed in construction documents. If the construction-document review does not verify that promise, the issue can disappear administratively without being resolved technically.

1.16 MODULE 1 PRACTICE CASE — THE CORRECTLY SIZED AIR HANDLER THAT CANNOT MEET THE OPERATING INTENT

Consider a multi-tenant office building with a variable-air-volume (VAV) air-handling unit.

The load calculations and equipment schedule appear reasonable. The unit capacity exceeds the modeled peak by a modest margin. The supply fan is variable-speed. The design uses a static-pressure sensor near the end of the main duct and a supply-air-temperature reset. Ventilation is provided at the air handler.

During design review, the following conditions are identified: the tenant occupancy is highly variable; several zones have unusually high minimum VAV settings; the outdoor-air schedule lists one design value but does not describe part-load control; the sequence resets static pressure but does not state the reset limits or the zone-request logic; the supply-air-temperature reset is based on outside air only; the outside-air damper has a minimum position but no airflow measurement; several perimeter zones have large glazing loads; the owner expects aggressive after-hours setback; and the system must recover quickly in the morning.

Nothing in this list proves that the design is wrong. But together, the conditions reveal that the system’s success depends more on controls and part-load behavior than on peak capacity.

A structured reviewer would ask:

1. How were VAV minimums established, and do they reflect ventilation or another constraint? 2. How will the air handler maintain required ventilation as total supply airflow changes? 3. What is the actual logic for resetting duct static pressure? 4. Are all VAV boxes capable of stable control across the intended range? 5. Could high minimums create simultaneous cooling and reheat? 6. Is the supply-air-temperature reset compatible with perimeter cooling demand? 7. How will morning recovery work after setback? 8. Which points will be trended during commissioning? 9. How will the functional test prove that the reset sequences respond to zone demand?

10. What will happen if the outdoor-air sensor or a critical zone sensor fails? The case illustrates the central principle of Module 1: HVAC design review should move from scheduled capacity to system behavior.

Module 1 Summary

A professional HVAC design review begins with operating intent and traces that intent through the calculations, system selection, equipment, distribution, controls, construction documents, and verification strategy.

The most important review habits are: start with the project requirements rather than the equipment schedule; review load assumptions, not merely peak totals; treat ventilation as both a design and control requirement; recognize that comfort depends on zoning, distribution, sensors, and environmental factors; evaluate part-load behavior; cross-check schedules against drawings and specifications; define redundancy by the failure condition the system must survive; treat service and replacement access as design requirements; include controls sequences in design review from the beginning; use a repeatable matrix; classify comments by consequence; and track comments through actual closure.

Module 2 moves from design intent to physical reality: whether the system can be built, coordinated, accessed, supported, drained, insulated, maintained, and replaced without sacrificing the performance assumed in the design

Equipment, Airside & Hydronic Constructability



Contextual photograph: Duct routing must preserve clearance, insulation, access and system performance; a photograph does not prove an installation is adequate.

2.1 CONSTRUCTABILITY IS THE TEST OF WHETHER DESIGN INTENT CAN SURVIVE THE BUILDING

Constructability is sometimes reduced to clash detection: does a duct intersect a beam, does a pipe pass through a light fixture, or can the equipment fit through the door? Those checks matter, but they are only the most visible layer.

For an HVAC engineer, constructability is broader. It asks whether the system can be installed, supported, insulated, accessed, connected, tested, adjusted, maintained, replaced, and operated without defeating the performance assumptions embedded in the design.

A system can be geometrically clash-free and still be poorly constructible.

Examples include: a valve located above an inaccessible hard ceiling; a coil pull that is blocked by electrical gear; a pump strainer that cannot be removed because of adjacent piping; an air-handling unit that fits through the construction opening but cannot be replaced after the wall is complete; a VAV box installed where the control enclosure cannot be opened; a hydronic balancing valve located where the technician cannot obtain meaningful differential-pressure readings; condensate piping routed with no practical drain path; access doors that exist on the drawings but are obstructed by structure, cable tray, ductwork, or piping; vibration isolators that cannot function because rigid connections bypass the isolation; a sensor installed where it measures a local condition instead of the controlled condition; and an equipment room so tightly packed that routine filter changes require removal of other components.

The constructability review therefore needs to test the system across its life cycle, not only through installation.

A useful question is:

“If this equipment is installed exactly as shown, can the owner operate and maintain the intended system for the next 20 years without improvising around our design?”

That question exposes issues that ordinary coordination often misses.

2.2 COORDINATION MODELS ARE TOOLS, NOT ENGINEERING DECISIONS

Building information modeling and clash-detection software can identify physical intersections with great precision. They cannot determine whether the coordinated layout is a good engineering solution unless the model includes the right constraints and a knowledgeable reviewer interprets the result.

A duct can be moved to avoid structure but gain excessive fittings and pressure loss. A pump can be relocated to create aisle clearance but produce a poor suction arrangement. A VAV box can be shifted out of a ceiling clash but become inaccessible for service. A control valve can fit physically but be installed with insufficient straight pipe for a flow-measurement device or in a location where the actuator is exposed to water. An air separator can be placed in open space but at the wrong hydraulic location.

A coordination process should therefore distinguish between:

1. physical clashes;
2. code or clearance conflicts;
3. service-access conflicts;
4. system-performance conflicts;
5. installation-sequence conflicts;
6. commissioning and test-access conflicts;
7. replacement-path conflicts. The engineer is particularly important for categories 4 through 7 because they require knowledge of system function.

2.3 EQUIPMENT ACCESS HAS THREE DIFFERENT MEANINGS



Installation access is only one condition. Lifecycle access separately includes routine service, major repair and full replacement.

“Access” is not one requirement.

For major HVAC equipment, the reviewer should distinguish:

Routine service access:

Can technicians reach filters, belts, bearings, actuators, sensors, strainers, traps, drain pans, control panels, and other recurring service items?

Major repair access:

Can motors, fans, coils, compressors, heat exchangers, pump rotating assemblies, tubes, large valves, or other major components be removed?

Replacement access:

Can the entire piece of equipment be removed and replaced at the end of its life? These three paths may be different.

A rooftop air handler may have excellent routine access but require crane replacement. A basement chiller may have acceptable tube-pull clearance yet no viable replacement route once the building is occupied. A fan coil above a ceiling may be serviceable from below but too large to remove through the access panel.

Design documents should not necessarily draw every future rigging plan, but they should avoid permanently trapping major equipment unless that choice is intentional and documented.

During review, identify: door and corridor dimensions; removable wall panels or louvers; roof hatches; freight elevators; equipment wells; knockout panels; crane access; removable piping sections; demountable ductwork; structural lifting points where applicable; laydown space; and maintenance aisles.

If replacement depends on temporary removal of building elements, the design team should know that before construction.

2.4 SERVICE CLEARANCES SHOULD BE BASED ON THE ACTUAL EQUIPMENT FUNCTION

Generic clearances are not enough. A manufacturer may provide minimum access clearances, but design review should consider the work being performed. Filter access requires enough room to withdraw the filter at its actual size and angle. Coil service may require removal of headers or entire coil sections. Heat-exchanger service may require tube-pull space. A pump may require room for coupling alignment or rotating-element removal. Electrical and control panels require applicable working clearances in addition to mechanical access. Actuators need room for removal and stroke. Dampers require access to linkages and blades.

A condensate pan requires access for inspection and cleaning. When multiple service zones overlap, the reviewer should verify whether simultaneous access is needed or whether the overlap is acceptable. A drawing note that says “maintain manufacturer clearances” can be useful, but it does not cure a layout that plainly cannot provide them.

2.5 EQUIPMENT ROOMS SHOULD BE REVIEWED AS WORKING ENVIRONMENTS

Mechanical rooms are not just containers for equipment. They are operating and maintenance environments.

A good mechanical-room layout considers: safe circulation; service zones; valve access; instrument visibility; floor drainage; housekeeping and cleaning; lighting; electrical panels and disconnects; overhead service; lifting; equipment removal; and noise. Additional considerations include heat rejection; ventilation; combustion-air needs where applicable; refrigerant safety where applicable; chemical treatment; water treatment; insulation; pipe expansion; controls panels; future capacity; and leak consequences.

The reviewer should imagine the room after insulation, controls conduit, electrical feeders, fire protection piping, and labels are installed. Early mechanical layouts often appear generous because only major equipment and primary piping are shown.

A 3D coordination model can help, but the reviewer should still perform a “technician walk-through” mentally or physically.

Ask:

- Where does the operator stand to read this gauge?
- Can the strainer basket be removed?
- Can this actuator be serviced?
- Can insulation be repaired?
- Where does water go if the coil is drained?
- Can the pump be aligned?
- Is a ladder required in a location where a ladder cannot be safely placed?
- Does maintenance block the room exit?
- Is the control panel visible from the equipment it controls?
- Can the owner add future equipment without dismantling the existing plant?

These questions convert space planning into operational design.

2.6 AIRSIDE CONSTRUCTABILITY STARTS WITH FLOW PATH AND PRESSURE CONSEQUENCES

Duct coordination often focuses on dimensions. The engineer should also review what routing changes do to the aerodynamic system. Every fitting, transition, damper, coil, filter, silencer, terminal unit, grille, diffuser, and length of duct contributes to system resistance. A duct that is rerouted during coordination may acquire: additional elbows; abrupt transitions; offsets; reduced cross-sectional area; higher velocity; additional dampers; and longer runs. The revised path may still “fit,” but it may no longer match the fan static-pressure basis or the intended acoustic performance.

This is especially important near fans and air-handling equipment. Poor inlet or discharge conditions can create system effects that are not represented by simple duct friction calculations. The reviewer should look for abrupt elbows, poor transitions, obstructions, unbalanced takeoffs, and geometry that can distort flow into equipment or measurement devices.

Constructability review should therefore include a change-control question:

“If coordination changes the distribution geometry materially, who rechecks the engineering consequences?”

Without that ownership, field-coordination decisions can silently become design changes.

2.7 CEILING CONGESTION IS AN INTERFACE PROBLEM

Ceiling spaces contain more than ductwork.

Typical competing systems include: structure; fire protection; plumbing; electrical feeders; cable tray; lighting; life-safety devices; access panels; ceiling supports; medical systems where applicable; and architectural features.

The mechanical engineer should identify which HVAC elements have geometric constraints that make them difficult to relocate.

Examples: large gravity condensate lines; outside-air ducts; smoke-control ducts; acoustically sensitive duct paths; equipment requiring access below; devices requiring straight duct lengths; sloped drainage; hydronic mains with expansion requirements; and ducts that cannot be reduced without unacceptable velocity or pressure loss.

Trade coordination works better when the project team knows these constraints early. A useful practice is to classify routes as: fixed; preferred; and flexible. A fixed route might be a large outside-air shaft or a gravity drain. A preferred route might be a main duct whose geometry is optimized but can move with engineering review. A flexible route might be a small branch duct that can be adjusted within reasonable limits. This prevents every system from entering coordination with the assumption that every other system should move.

2.8 DUCT ACCESS IS PART OF THE SYSTEM DESIGN

Airside systems include many devices that require future access: fire and smoke dampers; volume dampers; control dampers; coils; sensors; filters; UV or air-cleaning devices where used; terminal units; humidifiers; access doors; duct-mounted heaters; and airflow measurement devices.

A reviewer should verify both the device location and the access path. A ceiling access panel should be large enough and located so the technician can reach the device. The access panel should not be blocked by furniture, casework, lights, ceiling clouds, or architectural features. Device orientation matters. A damper actuator facing a wall may be technically accessible in a model but practically unserviceable. The same applies to VAV boxes. The controls enclosure, damper shaft, reheat coil, inlet sensor, and filter if provided all need realistic service access.

2.9 INSULATION REQUIRES SPACE TOO

Coordination models frequently represent duct and pipe outside dimensions without full insulation thickness, vapor barriers, jacketing, or installation tolerance. This can create problems after fabrication. For cold surfaces, insulation continuity is important to prevent condensation. If insulated pipes or ducts are packed tightly against structure or each other, the insulation may be compressed, omitted, or poorly sealed. Valves, flanges, unions, strainers, and equipment connections also require insulation treatment.

Reviewers should identify areas where: insulation thickness materially affects routing; vapor barriers are critical; removable insulation covers are needed for service; condensation could damage finishes or equipment; and external insulation may obstruct access.

Constructability is not complete until the as-insulated system fits.

2.10 CONDENSATE MANAGEMENT DESERVES DESIGN ATTENTION

Condensate systems are simple only when they work.

Design review should consider: available slope; trap configuration; pressure at the drain connection; cleanouts; air gaps or indirect connections where required; disposal location; overflow protection; secondary drainage where applicable; freeze risk; access for cleaning; and interaction with equipment curbs or housekeeping pads.

Negative-pressure drain pans require traps designed for the actual pressure relationship. Positive-pressure sections have different behavior. A field-installed trap selected by rule of thumb may be inadequate if the fan static pressure differs from expectations. The engineer should provide enough design intent that the installer is not forced to invent the drainage strategy. Rooftop and concealed equipment deserve particular scrutiny because condensate failures can damage the building before they are noticed.

2.11 HYDRONIC CONSTRUCTABILITY STARTS WITH HYDRAULIC FUNCTION

Hydronic piping is often coordinated visually, but the reviewer should preserve hydraulic function.

Important components include: pumps; isolation valves; control valves; balancing devices; strainers; air separators; expansion tanks; and vents. Additional considerations include drains; check valves; differential-pressure sensors; flow meters; temperature sensors; heat exchangers; and bypasses.

Each has a preferred functional relationship to the system. The constructability question is not merely whether they fit. It is whether their field location still supports the intended function. For example, moving a differential-pressure sensor to a convenient mechanical-room location can defeat a reset strategy intended to represent the hydraulically remote load. Relocating a flow meter without preserving required installation conditions can degrade measurement accuracy. Moving an expansion tank connection or air separator can change system behavior. Rearranging valves can make a pump impossible to isolate or a coil impossible to drain.

The engineer should identify critical functional relationships that should not be casually altered during coordination.

2.12 PUMP SUCTION AND DISCHARGE CONDITIONS SHOULD BE REVIEWED AS A SYSTEM

Pump problems are frequently blamed on the pump after installation even when the issue originates in piping configuration.

Constructability review should examine: suction piping geometry; air entrainment risk; high points; reducers; valves and strainers; available net positive suction head where relevant; and pump orientation. Additional considerations include flexible connectors; supports; alignment; vibration isolation; discharge check and isolation valves; pressure measurement; and access.

The exact requirements depend on pump type and manufacturer. The engineering principle is to provide stable, non-aerated flow into the pump and a serviceable installation. A model that places a pump

perfectly within a room is not enough if suction conditions create instability or if the pump cannot be removed without cutting permanent piping.

2.13 CONTROL VALVES ARE BOTH HYDRAULIC AND MAINTENANCE COMPONENTS

Control valves deserve attention because they sit at the interface between mechanical design and controls.

The reviewer should consider: design flow; pressure drop; valve sizing; authority; actuator type; fail position; and closeoff pressure. Additional considerations include control signal; rangeability; service access; orientation; isolation; strainer location where applicable; and measurement points.

Oversized control valves can create poor controllability even when the system has adequate capacity. A valve that operates mostly near its closed position may produce large flow changes from small stem movement. A valve selected only by line size can therefore undermine the control sequence. The constructability review should verify that the selected valve and actuator can be installed and serviced in the coordinated location and that the hydraulic design provides a useful operating range.

2.14 AIR MANAGEMENT, EXPANSION, AND FILL STRATEGY SHOULD BE TRACEABLE

Closed hydronic systems depend on appropriate expansion accommodation and air management. The reviewer should be able to identify: expansion-tank connection; fill connection; air-separation strategy; high-point vents; drain points; and pressure-control intent. Poor field placement can create persistent air problems, pressure instability, or difficult maintenance. The design should make the functional relationships clear enough that value engineering or coordination does not scatter components arbitrarily.

2.15 PIPE SUPPORT, EXPANSION, AND EQUIPMENT LOADS CROSS DISCIPLINES

Mechanical piping creates structural and architectural consequences.

Reviewers should consider: operating weight; test weight; seismic or wind restraint where applicable; thermal expansion; anchor loads; guide loads; and vibration. Additional considerations include roof penetrations; equipment curbs; slab openings; housekeeping pads; equipment inertia bases; and support spacing.

A hydronic main that fits through a corridor may still require anchors that cannot be attached to the available structure. A roof-mounted unit may fit architecturally while its curb, operating weight, wind load, and service path require structural changes. A large valve or strainer may need independent support. The mechanical engineer does not necessarily design all structural supports, but must communicate loads, movements, and required locations so that the structural solution is compatible with mechanical intent.

2.16 VIBRATION IS AN INTERFACE BETWEEN EQUIPMENT AND BUILDING

Vibration-control design can be defeated by one rigid path. An isolated pump may still transmit vibration through: rigid piping; electrical conduit; drain piping; supports; housekeeping pads; seismic restraints; and duct connections. Likewise, flexible connectors do not automatically solve vibration problems if the equipment base or piping layout is unstable. Constructability review should verify the complete isolation concept.

Questions include:

- What source is being isolated?
- What is the dominant frequency range?
- What isolator type and deflection are intended?
- Are pipe/duct connections compatible?
- Are restraints coordinated?
- Are supports placed so they do not short-circuit isolation?
- Will field installation preload or bind the isolators?

- Can the system be aligned correctly?

Acoustical performance should also be considered. High duct velocity, abrupt fittings, fan selection, terminal noise, structure-borne vibration, and mechanical-room placement can interact.

A quiet fan cannot compensate for a noisy system layout.

2.17 PHASING AND RENOVATION CREATE TEMPORARY HVAC SYSTEMS

Renovation projects often receive less constructability analysis than new construction even though they can be more complex.

Phasing can create temporary conditions such as: partial system operation; temporary cooling or heating; temporary ventilation; altered pressure relationships; blocked returns; temporary duct connections; repeated shutdowns; controls running in nonstandard configurations; occupied spaces adjacent to construction; temporary filtration; and water-system drain/refill cycles.

The permanent design may never show these operating states. Yet they can affect occupant safety, comfort, humidity, infection control where applicable, process stability, and equipment. The engineer should identify whether temporary conditions require engineered planning rather than leaving them entirely to field improvisation.

A renovation constructability review should ask:

- What must remain operational?
- What can be shut down?
- For how long?
- What temporary capacity is needed?
- What pressure relationships must be preserved?
- What sensors or controls will be unavailable during the phase?
- What temporary alarms are needed?
- How will permanent work connect without uncontrolled outages?
- How will the system be recommissioned after each phase?

2.18 SUBSTITUTIONS ARE SYSTEM CHANGES, NOT PROCUREMENT EVENTS

A substitution may be “equal” in capacity and still change the system.

Different equipment can have different: dimensions; weights; access requirements; electrical requirements; sound; pressure drops; and control interfaces. Additional considerations include turndown; minimum flows; startup requirements; refrigerant quantities; maintenance needs; and connection locations.

The reviewer should identify which parameters are critical to the system rather than relying on general “equal performance” language. For example, replacing a coil with one that has higher pressure drop may require more pump head. Replacing an air handler with different filter or coil pressure losses may affect fan performance. Replacing a variable-frequency drive (VFD) may affect BAS integration or bypass functionality. Replacing a rooftop unit may alter curb dimensions, weight, electrical load, condensate location, and service clearances.

A good substitution review asks:

“What else changes if we accept this product?”

2.19 SHOP DRAWINGS SHOULD BE REVIEWED FOR COORDINATION CONSEQUENCES

The engineer’s submittal review scope is defined by the contract and professional responsibility, but from a constructability perspective, shop drawings provide an important opportunity to compare actual selected equipment against design assumptions.

Useful review questions include:

- Do connection locations match the design?
- Are weights and dimensions consistent?

- Are service clearances feasible?
- Do fan and pump selections meet the specified duty?
- Are coil conditions correct?
- Are electrical characteristics coordinated?
- Are controls accessories included?
- Are minimum flows or turndown limits compatible with the sequence?
- Are sound levels acceptable?
- Does the submittal identify required factory options?
- Are drain connections and trap requirements coordinated?
- Are structural supports affected?
- Does the selected equipment create a new replacement/access issue?

The reviewer should avoid converting submittal review into manufacturer redesign. The objective is to determine whether the proposed product conforms to design intent and whether differences require engineering resolution.

2.20 CONSTRUCTABILITY COMMENTS SHOULD PRESERVE DESIGN RESPONSIBILITY

Mechanical engineers need to be careful when providing constructability comments during design and construction. A comment should identify the engineering concern without casually assuming means-and-methods responsibility that belongs elsewhere.

For example:

Appropriate:

“Maintain the required AHU coil service zone. Current routing of chilled-water supply/return (CHWS/CHWR) piping crosses the coil-removal path. Coordinate revised piping routing while maintaining design flow, valve access, insulation clearance, and support requirements.”

Less appropriate:

“Route the piping exactly 18 inches north and install two 90-degree elbows,” unless the engineer has actually designed and verified that routing. The first comment states the performance requirement and coordination constraint. The second may become an unintended design directive without full knowledge of field conditions. This boundary is project-specific, but clarity of responsibility protects both technical quality and project communication.

2.21 DEVELOP A CONSTRUCTABILITY REVIEW CHECKLIST

A practical checklist for HVAC systems can include:

EQUIPMENT

- installation path;
- routine service;
- major repair;
- replacement path;
- electrical clearance;
- controls access;
- drain access;
- lifting;
- housekeeping pads/curbs;
- structural loads.

AIR DISTRIBUTION

- duct routing;
- pressure-loss changes;
- fittings;
- transitions;
- access doors;

- dampers;
- terminal access;
- sensor location;
- insulation;
- acoustic considerations.

HYDRONICS

- pump layout;
- valve access;
- strainer removal;
- air management;
- expansion;
- vents/drains;
- control valves;
- balancing/measurement;
- sensor location;
- insulation;
- expansion/supports.

CONTROLS

- panel access;
- actuator access;
- sensor accessibility;
- tubing/wiring pathways;
- network interfaces;
- test points.

BUILDING INTERFACES

- structure;
- architecture;
- electrical;
- plumbing;
- fire protection;
- life safety;
- roofing;
- waterproofing.

LIFECYCLE

- startup;
- testing, adjusting, and balancing (TAB);
- commissioning;
- maintenance;
- replacement;
- future expansion.

2.22 MODULE 2 PRACTICE CASE — THE “FULLY COORDINATED” MECHANICAL ROOM

A coordinated model shows a small chilled-water mechanical room with no hard clashes. The room contains two base-mounted pumps, an air separator, expansion tank, control panel, chemical feeder, and several large isolation and control valves.

During detailed review, the engineer notices: pump suction piping has multiple close elbows; the strainer basket on one pump cannot be removed because it faces the wall; the second pump motor removal path is blocked by the expansion tank; the control panel door opens into the primary maintenance aisle; a differential-pressure sensor is shown in the room even though the control narrative intends remote-system pressure control; insulation thickness leaves almost no clearance between a valve actuator and adjacent piping; one drain valve discharges over electrical conduit; the piping layout leaves no practical

location to connect temporary flushing equipment; the expansion tank can be isolated by a normally open valve that is not identified as lock-open or otherwise protected from inadvertent closure; and the owner's only replacement path is through a door narrower than the pump base.

The model is clash-free but the design is not lifecycle-constructible.

A useful review would separate the findings:

Hydraulic performance: reconsider suction geometry and confirm differential-pressure sensor location. Maintenance: provide strainer, actuator, pump, and motor access and preserve replacement path. Safety/operations: coordinate drain discharge away from electrical equipment and protect critical expansion-tank connection from unintended isolation as appropriate to the design. Commissioning: provide access and connections necessary for flushing, measurement, and verification. Coordination: relocate the control panel or preserve the required working/maintenance area.

This case illustrates why constructability review requires mechanical engineering judgment after the clash-detection report says "zero conflicts."

Module 2 Summary

Constructability is the process of protecting engineering intent from physical reality.

A professional mechanical review should verify that: equipment can be installed, serviced, repaired, and replaced; mechanical rooms function as work environments; coordination changes do not silently alter pressure loss or system performance; duct devices remain accessible; insulation and vapor barriers have physical space; condensate can be reliably trapped, drained, cleaned, and monitored; hydronic components remain in functional relationships; pump arrangements support stable operation and maintenance; control valves are selected and located for both hydraulic performance and serviceability; air management and expansion strategy remain coherent; structure, vibration isolation, piping, and equipment supports are coordinated; temporary renovation phases receive engineering attention; substitutions are reviewed as system changes; shop drawings are used to verify actual equipment implications; and comments communicate required performance without casually assuming uncontrolled means-and-methods responsibility.

Module 3 follows the constructed system into performance: whether air and water can be distributed, measured, balanced, and controlled as intended after the design encounters real equipment, fittings, tolerances, and field conditions.

Distribution Performance, Balancing & Design-To-Field Reconciliation



Contextual photograph: Piping, instrumentation and valves provide context for evaluating distribution and controllability.

3.1 THE DISTRIBUTION SYSTEM IS WHERE DESIGN ASSUMPTIONS BECOME MEASURED PERFORMANCE

A fan, pump, coil, chiller, boiler, air handler, or terminal unit is selected at defined conditions. The building, however, is a network.

Air and water move through paths whose resistance depends on actual installed geometry, component positions, valve and damper settings, fouling, filters, fittings, elevation where relevant, control state, and simultaneous demand.

That difference between component selection and system behavior is one reason field performance can diverge from design even when every major piece of equipment is individually “correct.”

The engineer should therefore review distribution systems in terms of three connected questions:

1. Can the network deliver the required flow? 2. Can the flow be controlled over the expected operating range? 3. Can the performance be measured and verified? A system that cannot answer all three questions is difficult to commission and often difficult to troubleshoot.

3.2 FLOW FOLLOWS PRESSURE DIFFERENCE AND RESISTANCE, NOT DRAWING INTENT

Drawings show intended flow paths. They do not force air or water to take those paths in the intended quantities. At a conceptual level, flow through a branch depends on the pressure difference available to that branch and the resistance of the branch. When parallel branches have different resistance, flow distribution changes. When a balancing damper or valve adds resistance, flow redistributes. When a filter loads, system resistance changes. When VAV boxes close, the fan sees a different system. When two-way hydronic valves close, the pump system curve changes.

The design should anticipate these changes rather than assuming the balanced design condition is permanent. This is particularly important in variable-flow systems because the distribution network is intentionally changing.

3.3 FAN AND PUMP OPERATING POINTS ARE SYSTEM RESULTS

A fan or pump curve describes equipment performance. The system curve describes the pressure required by the distribution system at different flows. The actual operating point occurs where the equipment and system behaviors intersect. Design review should therefore avoid language such as “the pump produces 60 feet of head” as though head were a fixed output independent of flow. A centrifugal pump operating at constant speed can produce different head at different flows. Likewise, a fan’s pressure and airflow are linked by its performance curve and system resistance.

Variable-speed drives add flexibility, but they do not eliminate the need to understand system behavior.

For geometrically similar operating conditions, the familiar affinity relationships provide useful intuition: flow changes approximately in proportion to speed; developed pressure changes approximately with the square of speed; and power changes approximately with the cube of speed.

Real systems and equipment have limitations, and efficiency changes across the range, but the relationships explain why variable-speed control can reduce energy use at part load—and why poor control logic can also drive a fan or pump to unnecessary pressure.

3.4 DESIGN PRESSURE SHOULD INCLUDE REAL COMPONENTS

Distribution pressure calculations should be traceable to actual components. For air systems, the pressure budget may include: duct friction; fittings; filters; coils; heat-recovery devices; silencers; dampers; terminal units; diffusers/grilles; louvers; airflow stations; and specialty devices. For hydronic systems: pipe friction; fittings; coils; control valves; balancing devices; strainers; heat exchangers; meters; check valves; and other components. One review risk is that a component appears in the specification or submittal but not in the original pressure budget.

For example, a final filter selection may have substantially more pressure drop than the concept design assumed. A control valve may be selected with a different pressure drop. A sound attenuator may be added after acoustical review. A heat exchanger may change. If the pressure budget is not updated, the system may lose margin. The opposite problem also occurs: excessive pressure allowance can produce oversized fans and pumps that spend their operating life throttled or reset far below design. The goal is not a large margin. It is a defensible pressure basis.

3.5 BALANCING CAPABILITY MUST BE DESIGNED

Testing and balancing cannot create control authority that the design does not provide. A branch can only be balanced effectively if the system includes practical means to measure and adjust flow.

The reviewer should ask:

- Are balancing devices present where needed?
- Are they accessible?
- Is there enough pressure available?
- Are measurement ports usable?
- Are terminal devices within their controllable ranges?
- Can the system establish design flow without forcing another branch outside its range?

- Are minimum and maximum values clearly documented?
- Are devices selected for the actual range rather than nominal line or duct size?

A common design mistake is to assume a control valve, VAV damper, or manual balancing device can correct any distribution error. In reality, devices have operating ranges. A VAV box operating near fully open may have little remaining authority. A control valve operating near closed may be unstable. A manual balancing valve that must absorb excessive pressure can create noise or poor performance. Designing for balancing means designing a network with reasonable pressure relationships.

3.6 TAB IS A DIAGNOSTIC WINDOW, NOT A SUBSTITUTE FOR DESIGN

Testing, adjusting, and balancing provides measured information about the installed system. A strong engineering team treats TAB results as evidence.

A weak process treats TAB as a final subcontractor task expected to “make the numbers work.”

When a measured flow is wrong, several different causes are possible: design calculation error; incorrect equipment selection; installation error; duct leakage; pipe restriction; wrong valve/damper position; control command; and sensor error. Additional considerations include inadequate fan or pump pressure; unexpected pressure drop; reversed component; missing component; dirty filter/strainer; improper rotation; calibration error; and unmodeled field change.

The TAB technician can adjust devices, but should not be expected to diagnose or redesign every cause. The engineer should establish escalation criteria for conditions that cannot be corrected through ordinary balancing.

3.7 DISTINGUISH BALANCING ERROR FROM DESIGN OR CONTROL ERROR

Consider a VAV terminal that cannot achieve scheduled maximum airflow. A technician may open the damper fully.

If airflow remains low, possible causes include: insufficient duct static pressure; upstream damper restriction; duct obstruction; poor inlet conditions; incorrect flow-sensor setup; undersized duct; excessive pressure loss; fan operating point; calibration; and actual box size differing from schedule.

Now consider a terminal that achieves design airflow during TAB but produces comfort complaints later.

The problem may be: incorrect minimum airflow; poor zone grouping; sensor location; unstable reheat control; supply-air temperature reset; occupancy schedule; solar load; diffuser performance; and simultaneous heating/cooling logic.

The ability to reach a design airflow once does not prove the system controls correctly. TAB and controls must be interpreted together.

3.8 VAV SYSTEMS SHOULD BE REVIEWED AS DYNAMIC NETWORKS

Variable-air-volume systems change resistance as dampers modulate. The supply fan must respond to the changing network. One common strategy controls duct static pressure. A fixed static-pressure setpoint can work, but it may waste energy if the pressure is set for the worst design condition at all times. Reset strategies can reduce pressure when zones do not need it. The engineering question is how the reset knows when to increase or decrease pressure. Possible approaches use information such as: VAV damper positions; zone requests; critical-zone status; pressure at a representative location; and combinations of the above.

Guideline 36-2024 is one example of a systematic approach to high-performance sequences, including reset concepts intended to reduce excess pressure and improve control stability. Regardless of the chosen sequence, the reviewer should verify: minimum and maximum static-pressure limits; sensor location; signal validity; request logic; response rate; alarm behavior; and fallback behavior. A reset with no bounds or failure strategy is incomplete.

3.9 SENSOR LOCATION DETERMINES WHAT THE CONTROL SYSTEM BELIEVES

Sensors are not abstract points. A duct-static sensor near the fan measures something different from a sensor near the hydraulically or aerodynamically remote part of the system. A differential-pressure sensor across a hydronic loop can represent different system needs depending on where its taps are located. A mixed-air temperature sensor can be affected by stratification. A space-temperature sensor can be influenced by sun, walls, doors, equipment, or airflow. An outside-air temperature sensor can be heated by sun or building exhaust. A CO2 sensor can represent only its local zone.

The design review should ask whether the sensor location produces the information needed by the sequence. A precise sensor in the wrong location is still wrong information.

3.10 MEASUREMENT SHOULD BE DESIGNED FOR THE QUESTION BEING ASKED

Commissioning and troubleshooting are easier when the system contains useful measurement points.

Examples include: pressure taps; temperature wells; flow meters; airflow stations; BAS points; valve position; damper position; fan/pump speed; current/power where useful; supply/return temperatures; and zone conditions.

The engineer should distinguish between measurement used for control and measurement used for verification. A control loop may not require a permanent flow meter, but commissioning may still need a reliable way to verify flow. Conversely, a BAS point may display a calculated or commanded value rather than an independently measured physical quantity. The commissioning plan should identify what evidence is necessary.

3.11 CONTROLLED VALUES AND MEASURED VALUES ARE NOT THE SAME

A BAS may show:

“Chilled-water (CHW) valve = 50%.”

That is a control command or actuator position. It is not 50% flow.

A BAS may show:

“Outdoor-air damper = 30%.”

That is not necessarily 30% outdoor air.

A VFD may show:

“Fan speed = 60%.”

That is not necessarily 60% design airflow. The relationship depends on system resistance, device characteristics, calibration, and conditions. Engineers should avoid interpreting control-position values as direct performance values unless the relationship is established. This distinction becomes crucial during troubleshooting.

3.12 VALVE AUTHORITY AFFECTS CONTROLLABILITY

For a modulating hydronic control valve, useful control depends in part on the pressure drop across the valve relative to the rest of the controlled circuit. If the valve pressure drop is extremely small compared with available pressure, small valve movements may create disproportionately large flow changes. The loop can become difficult to control. If the valve pressure drop is unnecessarily large, pumping energy may increase. The design should therefore consider valve sizing as a control problem, not only a pipe-size problem.

Pressure-independent control valves can address some variability by regulating flow over an operating pressure range, but they still require appropriate selection, minimum differential pressure, commissioning, and maintenance.

No valve technology eliminates the need for system design.

3.13 HYDRONIC DIFFERENTIAL-PRESSURE CONTROL SHOULD REPRESENT ACTUAL DEMAND

Variable-primary or variable-flow hydronic systems commonly use differential-pressure control. A poorly selected sensor location can cause excessive pump pressure. If the sensor is near the pumps, it may not represent the remote branch. If the setpoint is fixed at a value sufficient for design peak, the system may maintain unnecessary pressure during most operating hours. A reset approach can reduce setpoint based on valve positions or load requests.

Review questions include:

- Where is differential pressure sensed?
- Why was that location chosen?
- What minimum/maximum setpoints apply?
- What are the critical circuits?
- Are valve position signals reliable enough for reset?
- What happens if communication fails?
- Is there a fallback pressure?
- Are low-flow equipment constraints protected?

The strategy should preserve both controllability and equipment requirements.

3.14 LOW-FLOW CONDITIONS CAN EXPOSE HIDDEN DESIGN PROBLEMS

Many HVAC problems appear at low load rather than peak load.

Airside examples: fan cannot turn down far enough; minimum VAV flows remain too high; outside-air fraction becomes excessive; cooling coil control becomes unstable; reheat increases; humidity control degrades; and fan pressure remains too high.

Hydronic examples: pump minimum speed is still excessive; chiller minimum flow becomes limiting; boilers short-cycle; control valves have poor authority; bypass flow dominates; differential pressure rises; and temperature differential degrades.

A design review should identify minimum stable operating conditions, not only maximum capacity.

3.15 DELTA-T PERFORMANCE IS A SYSTEM INDICATOR, NOT A SINGLE-COMPONENT METRIC

In chilled-water systems, a lower-than-expected temperature difference between supply and return is often called “low delta-T.”

The symptom can result from many causes: excess flow; control valves; coil selection; coil fouling; airside performance; sensor error; mixing/bypass; system configuration; load profile; and sequence.

It should not automatically be attributed to one component.

A useful troubleshooting approach is to follow energy through the system:

- Is load actually present?
- Is water flow measured accurately?
- Are temperatures measured accurately?
- Are valves modulating as expected?
- Are coils transferring heat?
- Is airside flow correct?
- Is bypass/mixing occurring?
- Is the plant staging compatible with the current load?

The same system-level reasoning applies to hot-water loops.

3.16 SUBMITTALS CAN CHANGE DISTRIBUTION PERFORMANCE

Equipment substitutions and final selections can change: coil pressure drop; heat-exchanger pressure drop; fan pressure; filter pressure; valve pressure; equipment minimum flow; and connection size.

Those changes should be reconciled with the distribution calculations.

The submittal process should not be a one-way check that “capacity meets schedule.”

It is also an opportunity to update the system model.

3.17 FIELD CHANGES SHOULD TRIGGER ENGINEERING RECONCILIATION WHEN THEY AFFECT PERFORMANCE

Field changes occur because buildings are complex. Not every duct offset or piping adjustment needs a formal redesign. The engineer should establish which changes are material.

Examples likely to merit engineering review include: significant duct-size reduction; multiple additional fittings in a critical path; major change to fan or pump selection; relocation of a critical sensor; changed control valve; changed terminal-unit size; and changed minimum flow. Additional considerations include added filter or silencer; alternate coil; changed heat exchanger; major routing change; changed equipment elevation that affects drainage; revised sequence; and revised outside-air strategy.

The threshold is consequence, not drawing appearance.

3.18 AS-BUILT PERFORMANCE SHOULD BE RECONCILED WITH DESIGN INTENT

At project completion, measured data should answer whether the installed system reasonably matches the intended system.

Useful information can include: final TAB report; fan speeds; pump speeds; actual flows; system pressure; valve/damper positions; setpoints; sensor calibration; control sequences; functional-test results; and unresolved deficiencies.

The engineer or commissioning team should look for conditions that technically “pass” but indicate weak margin.

For example: fan at 100% speed to barely achieve design flow; all balancing dampers fully open; pump at maximum speed; critical control valves fully open at ordinary load; extreme static-pressure setpoint; outside-air damper at limit; and persistent override.

A system operating at its limit during initial commissioning has little tolerance for filter loading, fouling, changed occupancy, or future degradation.

3.19 TREND DATA CAN REVEAL DYNAMIC PROBLEMS TAB CANNOT

TAB is generally a snapshot. Trend data can show behavior over hours or days.

Useful trends may include: space temperature; setpoint; discharge-air temperature; supply-air temperature; outdoor temperature; humidity; and fan/pump command and feedback. Additional considerations include static or differential pressure; damper/valve commands; airflow; occupancy mode; equipment stage; and alarms.

Trend review can reveal: hunting; simultaneous heating and cooling; unstable resets; poor morning recovery; short cycling; unnecessary night operation; sensors drifting; overrides; excessive pressure; and poorly coordinated staging.

Engineers should specify trend intervals and duration based on the phenomenon being investigated. A five-minute interval may be useful for some building-level behavior but too slow for a fast control loop. Trend design is therefore part of the verification plan.

3.20 DIAGNOSTIC THINKING: FOLLOW CAUSE FROM LOAD TO CONTROL

DIAGNOSTIC STEP	QUESTION TO RESOLVE
1 Confirm symptom	What is actually wrong?
2 Confirm measurement	Is the sensor or reading credible?
3 Reconstruct design intent	What should happen?
4 Check physical installation	Was the intended system built?
5 Check distribution	Can air or water reach the load?
6 Check control commands	What is the BAS asking equipment to do?
7 Check feedback and proof	Did the physical result occur?
8 Check commissioning evidence	Was this mode tested?
9 Correct the mechanism	Design, installation, controls, operation or maintenance.
10 Verify the correction	Retest and update accepted records.

A useful HVAC troubleshooting sequence is:

1. Confirm the complaint or observed failure. 2. Confirm the measured condition is real. 3. Confirm the load/operating context. 4. Confirm equipment availability and capacity. 5. Confirm distribution. 6. Confirm control commands. 7. Confirm sensors/feedback. 8. Confirm sequence logic. 9. Confirm interactions with other systems. 10. Confirm whether the condition is design, installation, control, operation, or maintenance. Skipping step 2 is common. An inaccurate sensor can send the entire investigation in the wrong direction. Skipping step 3 is also common.

A system may be performing correctly for an unusual condition that exceeds the original design basis. The goal is not to assign blame quickly. It is to identify the physical and control mechanism producing the condition.

3.21 MODULE 3 PRACTICE CASE — THE VAV BOXES ARE “ALL OPEN”

A new office project reports warm zones on the top floor. The BAS shows several VAV dampers at 95–100% during afternoon periods. The supply fan is at 90% speed. Duct static pressure is at its setpoint. The supply-air temperature is also at setpoint. Possible reactions include increasing static pressure or lowering supply-air temperature. A structured investigation asks more questions first. 1. Are the VAV airflow measurements calibrated? 2. Are the boxes actually receiving the commanded airflow? 3. Are the warm zones concentrated in one duct branch? 4. Did coordination add pressure loss to that branch?

5. Is the duct-static sensor located where it represents the critical path? 6. Is the static-pressure setpoint reset logic functioning? 7. Are the terminal-unit design airflows correct for actual loads? 8. Did tenant changes increase loads? 9. Is supply-air temperature appropriate for current humidity and reheat behavior? 10. Are diffusers delivering air effectively to the occupied zone?

Assume the investigation finds: the critical top-floor branch received two additional offsets during coordination; the static-pressure sensor remained in its original upstream location; downstream boxes are fully open; upstream boxes are partially closed; fan capacity is adequate; and the static-pressure reset cannot “see” the remote branch deficiency.

The problem is not a VAV-box failure. It is a distribution and control-sensor problem. A defensible solution may involve relocating or adding sensing, revising reset logic, or addressing branch resistance.

Simply increasing a fixed setpoint could mask the issue while increasing energy use and pressure throughout the system.

3.22 MODULE 3 PRACTICE CASE — CHILLED-WATER VALVES HUNT AT LOW LOAD

A building has two-way control valves and variable-speed pumps. During light-load conditions, several coil valves cycle between nearly closed and moderately open. Differential pressure remains high. The BAS indicates pump speed is 55%. Possible causes include: differential-pressure (DP) setpoint too high; DP sensor poorly located; oversized control valves; unstable loop tuning; low coil load; pump minimum speed too high; bypass path; and sensor noise. The engineer should not immediately tune the proportional-integral-derivative (PID) loop. First determine whether the hydraulic system gives the valve a controllable operating range.

If excessive pressure is forcing valves near closed, tuning the temperature loop may only treat the symptom. A better resolution could involve DP reset, sensor relocation, valve review, pump-minimum review, or a combination. This case illustrates a key course principle: many “controls problems” are mechanical design problems expressed through controls.

Module 3 Summary

HVAC distribution performance is the connection between equipment selection and actual building behavior.

A strong engineer recognizes that: flow follows pressure difference and resistance; fan and pump operating points result from equipment/system interaction; pressure budgets should reflect real components; balancing capability must be designed; TAB provides evidence but is not a substitute for design; variable-flow systems should be reviewed dynamically; sensor location determines the information available to controls; position signals do not equal measured performance; control-valve sizing affects controllability; differential-pressure strategy should represent actual demand; low-load operation can expose design weaknesses hidden at peak; delta-T symptoms require system-level diagnosis; submittals and field changes can alter distribution performance; final measured performance should be reconciled with design intent; trend data is essential for many dynamic problems; and troubleshooting should separate measurement, load, equipment, distribution, controls, and operation before assigning cause.

Module 4 now moves deeper into the control layer: how sequences of operation convert the engineer’s intent into logic that the building automation system can execute and the commissioning team can test.

HVAC Controls, Sequences Of Operation & BAS Integration



Contextual photograph: A control-panel detail illustrates the distinction between an operator interface and verified system behavior.

4.1 A SEQUENCE OF OPERATION IS AN ENGINEERING DELIVERABLE

An HVAC sequence of operation is the written description of how the physical system should behave. It is not merely a controls-contractor instruction. The sequence connects: design intent; sensors; actuators; equipment enable conditions; setpoints; resets; safeties; alarms; occupancy schedules; failure responses; operator interaction; and commissioning tests. If the sequence is vague, the controls contractor must interpret the engineer's intent. Two competent programmers can read the same vague sentence and create different systems.

For example:

"Reset supply-air temperature based on building load."

That statement does not define: the reset range; the load indicator; how many zones must request change; how fast the setpoint changes; what happens at limits; whether humidity overrides apply; what happens during warm-up; and what happens when a zone signal fails.

A reviewable sequence should be specific enough that another engineer can predict the system response before the BAS is programmed.

4.2 START WITH OPERATING MODES

One of the clearest ways to review a sequence is to identify every operating mode.

Possible modes include: occupied; unoccupied; standby; warm-up; cooldown; morning recovery; night setback/setup; and economizer. Additional considerations include dehumidification; smoke control; purge; freeze protection; emergency; equipment failure; and maintenance override.

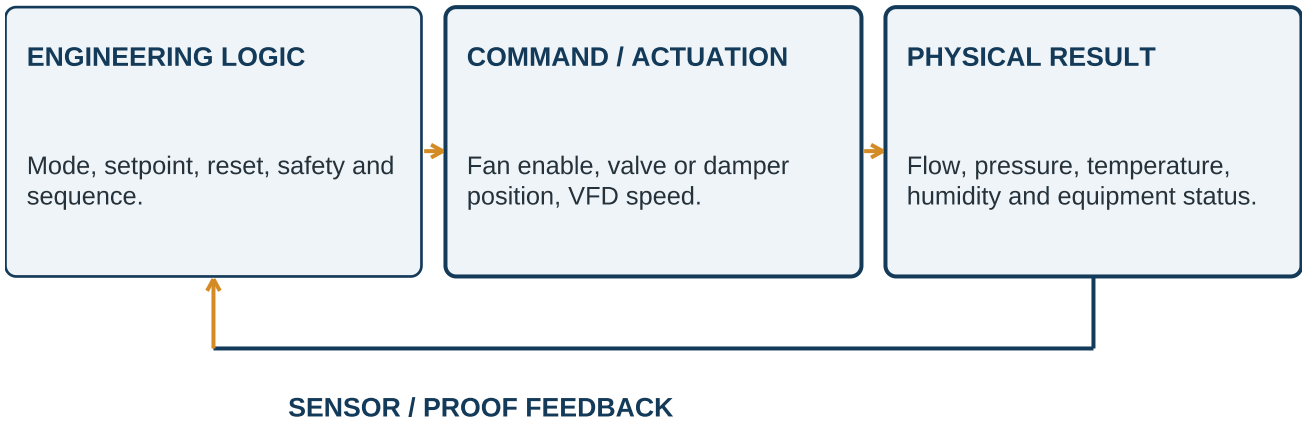
Not every system needs every mode. The important point is to define which modes exist and how transitions occur. Mode-transition defects are common because sequences often describe steady-state control better than transitions.

Questions include:

- What causes entry into the mode?
- What causes exit?
- Is there a delay?
- Which commands change?
- Which safeties remain active?
- What happens if conditions change before the transition completes?
- Can two modes conflict?
- Which mode has priority?

A building may perform correctly most of the day and fail every morning because the warm-up transition is poorly defined.

4.3 ENABLE LOGIC SHOULD DISTINGUISH COMMAND FROM PROOF



A BAS command is not evidence that the intended condition occurred. Feedback must verify the required physical result.

“Enable the fan” is not the same as “the fan is operating.”

A control sequence should distinguish: command; status/proof; and resulting condition.

For a supply fan:

1. BAS issues enable command. 2. VFD or starter receives command. 3. fan status or proof indicates operation. 4. airflow/static pressure begins to develop. 5. dependent sequences become active. If step 3 fails, should heating or cooling valves open? Should an alarm occur? Should the outdoor-air damper remain closed? Should another fan start? The answer depends on the design, but the sequence should define it. The same principle applies to pumps, chillers, boilers, compressors, exhaust fans, dampers, valves, and other equipment. Controls become more robust when dependencies use verified state where appropriate rather than assuming a command succeeded.

4.4 SENSOR QUALITY IS PART OF CONTROL DESIGN

Controls depend on measurements. A sequence should identify: what is measured; where it is measured; expected range; required accuracy where relevant; and what happens when the signal is invalid. Common HVAC sensors include: temperature; humidity; pressure; differential pressure; airflow; flow; CO2; occupancy; current; position; and refrigerant or safety sensors where applicable. The design should consider failure detection. A sensor can fail: high; low; frozen at one value; intermittently; gradually drifting; physically disconnected; and communicating but incorrect. Some failures are obvious.

A space temperature of -40°F is implausible in an occupied office. A sensor frozen at 72°F can be harder to detect. Redundant sensors, plausibility checks, rate-of-change checks, comparison to related variables, or alarms can improve detection for critical systems. Not every sensor requires sophisticated diagnostics. The review should focus on sensors whose failure can create significant performance, safety, or energy consequences.

4.5 ACTUATORS AND FAILURE POSITIONS SHOULD MATCH SYSTEM RISK

Control sequences often specify normal modulation but omit failure behavior.

Important questions include:

- What happens on loss of power?
- What happens on loss of control signal?
- What position should a valve or damper assume?
- Is spring return needed?
- What happens after power restoration?
- Does the BAS know actual position or only command?

A heating valve that fails open may create overheating. A cooling valve that fails closed may create loss of cooling. An outside-air damper that fails open may expose coils to freezing conditions in some climates. A smoke-control damper may have life-safety requirements outside the ordinary HVAC sequence. There is no universally correct fail position. The design should select failure behavior based on consequence.

4.6 SETPOINTS SHOULD HAVE PURPOSE, RANGE, AND OWNERSHIP

Every setpoint should answer:

- What condition is it controlling?
- What is the normal value or range?
- Who can change it?
- What limits apply?
- Is it reset?
- Is it scheduled?
- Is it overridden by another mode?
- Is it trended?

Uncontrolled setpoint proliferation is a common BAS problem. If operators can change every internal parameter without guidance, the system may drift far from design intent. Conversely, locking every setpoint can make operation impractical. A useful design distinguishes: operator-adjustable values; commissioning values; protected engineering constants; calculated values; and temporary overrides. The systems manual or sequence documentation should preserve the intended values and limits.

4.7 RESET STRATEGIES SHOULD REDUCE EXCESS WITHOUT LOSING CONTROL

Reset strategies are powerful because design conditions occur only a fraction of the time.

Examples include resetting: supply-air temperature; duct static pressure; hydronic differential pressure; hot-water temperature; chilled-water temperature; condenser-water temperature; and ventilation quantities where allowed and appropriate.

A reset should define:

1. the controlled setpoint;
2. the reset range;
3. the demand indicator;
4. the response logic;
5. the rate or step size;
6. minimum/maximum limits;

7. override conditions;

8. failure fallback. The reviewer should test reset logic against extreme and ordinary conditions. For example, a supply-air-temperature reset that raises temperature aggressively at light load can reduce cooling and reheat but may increase airflow demand. That higher airflow can increase fan energy. The "best" reset depends on the interaction among cooling, heating, fan energy, humidity, and zone demand. The point is not to memorize one strategy. The point is to review the whole-system consequence.

4.8 GUIDELINE 36 SHOWS WHY STANDARDIZED SEQUENCES CAN IMPROVE PERFORMANCE

ASHRAE Guideline 36-2024, together with the applicable published addenda and errata, provides uniform high-performance sequence guidance intended to improve energy efficiency, control stability, and fault detection.

Even when a project does not use Guideline 36 directly, it illustrates several valuable design principles: sequences should be explicit; resets should respond to actual demand; setpoints should be bounded; zone requests can be aggregated; alarms should identify meaningful faults; overrides should be visible; logic should avoid unnecessary simultaneous heating and cooling; and control states should support diagnostics.

The engineer should not copy a standardized sequence without understanding whether the physical system matches its assumptions. Standardization is most useful when it reduces ambiguity while preserving engineering judgment.

4.9 PID CONTROL: REVIEW THE PROCESS BEFORE TUNING THE LOOP

Proportional-integral-derivative control is widely used in HVAC systems.

A complete mathematical treatment is outside this course, but engineers reviewing controls should understand the functional roles:

Proportional action responds to current error. Integral action responds to accumulated error and helps eliminate steady-state offset. Derivative action responds to rate of change and is used selectively because noise and practical tuning considerations can limit its usefulness.

When a loop hunts, oscillates, or responds poorly, the immediate reaction is often "tune the PID."

But unstable behavior may result from: oversized valve/damper; poor sensor location; excessive system pressure; actuator problems; deadband; slow thermal process; conflicting loops; minimum flow; sampling/update rate; and mechanical fault.

Tuning cannot correct a fundamentally poor process. The reviewer should first ask whether the controlled variable, sensor, actuator, and physical system are appropriate.

4.10 CASCADING LOOPS REQUIRE CLEAR HIERARCHY

HVAC systems contain interacting loops.

Examples: space temperature drives VAV airflow; VAV demand drives duct-static reset; duct static drives fan speed; zone demand drives supply-air-temperature reset; and supply-air temperature drives cooling-valve position.

Hydronic systems may include: zone/coil temperature; valve position; differential-pressure reset; pump speed; plant staging; and supply-water-temperature reset. If loops operate at similar speeds or respond to the same symptom without hierarchy, they can fight. The engineer should understand which loop is primary and which loop supports it. Reset logic should usually change more slowly than the local control loop it is supervising. Otherwise, the target can move faster than the local loop can settle.

4.11 OCCUPIED AND UNOCCUPIED OPERATION SHOULD BE EXPLICIT

Buildings do not need identical HVAC operation at all times. Unoccupied sequences may: relax temperature setpoints; reduce ventilation; stop fans; maintain humidity or freeze protection; respond to special loads; and cycle equipment. The sequence should define: schedule source; holiday handling;

tenant overrides; after-hours requests; maximum override duration; recovery logic; and minimum safeguards. After-hours overrides are a common source of unnecessary energy use. If an override starts the entire building for one small zone, the design may be inefficient.

If the override expires without warning or cannot provide needed ventilation, occupants may complain. The review should match override scope to system topology.

4.12 MORNING WARM-UP AND COOLDOWN SHOULD REFLECT BUILDING RESPONSE

Morning recovery is a transition problem. A building starting after setback may need: heating; cooling; dehumidification; air circulation; and ventilation. The sequence should define whether outdoor air is reduced during warm-up where permitted and appropriate, how zone demand is evaluated, and when normal occupied operation begins. A common mistake is to start occupied ventilation immediately even when the building is far from temperature setpoint. Another is to delay ventilation too long after occupants arrive. The appropriate strategy depends on code, occupancy, climate, and system.

The important review question is whether the sequence matches actual building recovery.

4.13 ECONOMIZER CONTROL IS MORE THAN "OPEN OUTSIDE AIR WHEN COOL"

An economizer uses outdoor conditions to reduce mechanical cooling when appropriate.

Review considerations can include: temperature or enthalpy criteria; high-limit logic; mixed-air control; minimum outdoor air; return/exhaust relief; fan interaction; humidity implications; sensor accuracy; freeze protection; and mechanical-cooling integration.

A poor sequence can create simultaneous economizer and mechanical cooling, excessive outdoor air, building pressure problems, or humidity issues. The engineer should define how the system transitions among minimum ventilation, economizer operation, and mechanical cooling. The design should also consider failure of outdoor-air sensors. An inaccurate outdoor-air signal can keep an economizer disabled when beneficial or enabled when harmful.

4.14 DEMAND-CONTROLLED VENTILATION REQUIRES MORE THAN A CO2 SENSOR

Demand-controlled ventilation can reduce outdoor-air delivery when occupancy is lower than design under conditions permitted by the governing requirements.

A robust design considers: which zones are suitable; sensor location; outdoor concentration assumptions or measurement strategy; minimum area-based ventilation; system ventilation efficiency; response time; occupancy patterns; calibration; failure mode; and integration with total system outdoor airflow.

A CO2 sensor should not be treated as a universal indoor-air-quality sensor. CO2 can be useful as an occupancy-related ventilation indicator, but many indoor contaminants are unrelated to occupancy. The sequence should preserve any required non-occupant-related ventilation. ASHRAE Standard 62.1-2025 includes updated demand-control-ventilation control-sequence requirements, making it particularly important that engineers review the actual logic rather than only specify hardware.

4.15 HUMIDITY CONTROL CAN OVERRIDE TEMPERATURE-ONLY LOGIC

In humid climates, a system can maintain temperature and still fail moisture control. Humidity behavior depends on: coil leaving conditions; airflow; ventilation; infiltration; latent load; reheat; equipment cycling; supply-air-temperature reset; and building pressure. A supply-air-temperature reset that raises the setpoint during light sensible load can reduce latent removal. A cycling unit may satisfy thermostat demand before enough moisture is removed. Excess outdoor air can increase latent load. Poor building pressure can increase infiltration.

The sequence should identify whether humidity control is required and how it interacts with temperature control. Dehumidification logic should not be improvised after complaints occur.

4.16 LEAD/LAG LOGIC SHOULD DEFINE ROTATION AND FAILURE RESPONSE

Multiple pumps, chillers, boilers, compressors, or air-handling units often use lead/lag control. A complete sequence should define: how lead equipment is selected; rotation frequency; runtime equalization; staging criteria; proof; failure response; restart behavior; manual lockout; and maintenance mode. A simplistic sequence that rotates equipment every week may create an undesirable transition under peak conditions. Runtime-based rotation may be more appropriate in some systems. The engineering intent should be explicit.

4.17 STAGING SHOULD INCLUDE BOTH LOAD AND EQUIPMENT LIMITS

Equipment staging should not be based only on one temperature. Useful inputs may include: load estimate; equipment loading; valve positions; flow; temperature; runtime; rate of change; efficiency; and minimum on/off times. The sequence should avoid short cycling. For example, staging a second chiller immediately when supply-water temperature rises slightly can cause unnecessary cycling if the first chiller has not reached stable capacity. Conversely, waiting until the lead machine is fully saturated may produce poor control. The exact logic is system-specific.

The review should verify that staging reflects equipment operating limits and process response.

4.18 SAFETIES SHOULD OVERRIDE NORMAL CONTROL IN A DEFINED ORDER

HVAC equipment includes safety functions that may be: hardwired; factory controlled; BAS controlled; code mandated; and manufacturer required. Examples include: freezestats; high/low pressure; smoke shutdown; high static pressure; low flow; freeze protection; condensate overflow; motor protection; refrigerant detection; and fire alarm interlocks. The engineer should identify how BAS logic interacts with independent safeties. A BAS should not casually defeat a manufacturer or life-safety protection.

The sequence should define: which safety has priority; what shuts down; what remains operating; what alarms; whether automatic reset is allowed; and whether manual reset is required.

4.19 ALARMS SHOULD BE ACTIONABLE

An alarm is useful when it tells an operator that something meaningful happened and what level of response is appropriate. Poorly designed BAS alarm systems generate: too many alarms; repetitive alarms; nuisance alarms; alarms with no clear cause; and alarms that clear before anyone sees them. Operators eventually ignore them. A good alarm strategy considers: severity; delay; deadband; suppression during known transitions; escalation; acknowledgment; persistence; and recovery. For example, a zone temperature 0.5°F above setpoint for two minutes is rarely an emergency.

A fan commanded on with no proof for several minutes may require prompt attention. An engineering review should focus on abnormal conditions that affect safety, equipment, comfort, or performance.

4.20 TRENDING SHOULD BE SPECIFIED AS PART OF THE VERIFICATION STRATEGY

Trend logs are essential for commissioning and troubleshooting, but only if the right points are stored at useful intervals. The engineer should identify critical points.

For a VAV air handler, useful trends can include: supply-air temperature; supply-air setpoint; duct static pressure; static-pressure setpoint; fan speed; outdoor air temperature; and mixed-air temperature where used. Additional considerations include outdoor-air command; representative zone temperatures; representative VAV flows; damper positions; heating/reheat commands; and occupancy mode.

For a hydronic plant: supply/return temperatures; differential pressure; DP setpoint; pump speed; valve positions; equipment enable/status; flow where measured; stage; and outdoor conditions.

Trend storage should be planned. High-frequency data can consume storage rapidly. Low-frequency data can miss oscillations. Some points can use change-of-value logging. Others need fixed intervals.

4.21 MANUAL OVERRIDES SHOULD BE VISIBLE AND SELF-DISCIPLINED

Overrides are necessary during maintenance, commissioning, and emergency operation. They are also a frequent cause of long-term performance problems. An engineer can reduce risk by requiring: clear override indication; user identification; time/date; expiration where appropriate; alarm or status flag; and easy return to automatic mode. A hidden override that persists for months can defeat an otherwise excellent sequence. Examples include: outside-air damper forced closed; pump forced on; valve forced open; supply-air-temperature setpoint fixed; and alarm disabled. The BAS interface should make manual conditions easy to discover.

4.22 INTERFACES BETWEEN SYSTEMS REQUIRE RESPONSIBILITY

HVAC controls may interact with: fire alarm; smoke control; electrical power; emergency generator; lighting; access control; occupancy systems; laboratory controls; kitchen exhaust; elevators; process systems; and metering.

Each interface should identify: source of signal; receiving system; normal state; abnormal state; priority; proof; failure behavior; and testing responsibility. Integration problems often occur because each trade assumes the other will provide a signal. An interface matrix can make responsibilities explicit.

4.23 BAS NETWORK ARCHITECTURE AFFECTS RESILIENCE

Modern building automation systems are networked. The course is not a cybersecurity course, but mechanical engineers should understand basic operational implications.

Questions include:

- Can equipment operate locally if the network is lost?
- Which controllers depend on supervisory servers?
- Are critical setpoints stored locally?
- What happens if communications fail?
- Are time schedules local or server-based?
- What happens after a controller reboot?
- Are default values safe and appropriate?

A robust mechanical design avoids making basic safe operation dependent on a single supervisory connection unless that dependency is intentional.

4.24 CONTROLS SUBMITTAL REVIEW SHOULD TRACE EVERY POINT TO DESIGN INTENT

Controls submittals can be large.

A structured review can trace:

1. equipment;
2. control diagram;
3. points list;
4. sequence;
5. network/interface;
6. alarms;
7. trends;
8. graphics.

The reviewer should ask:

- Is every required sensor shown?
- Is every required actuator shown?
- Are device ranges appropriate?
- Are fail positions correct?

- Do point names align with the sequence?
- Are safeties included?
- Are alarms defined?
- Are trends included?
- Are setpoint limits clear?
- Are interlocks documented?
- Are third-party interfaces included?
- Are graphics planned to show meaningful state?

A point list with hundreds of points is not proof of a complete controls design. Completeness means the points can execute and verify the sequence.

FACTORY CONTROLS AND BAS INTEGRATION BOUNDARIES

Many HVAC products arrive with factory-installed controllers. Packaged rooftop units, chillers, boilers, variable-refrigerant systems, heat pumps, pumps, and other equipment may have substantial local logic before the building automation system (BAS) is connected.

That creates an interface boundary that should be engineered explicitly.

The design team should identify which functions remain under the factory controller and which functions are assigned to the BAS. Typical interface questions include:

- Does the BAS issue only enable/disable commands, or can it write operating setpoints?
- Which safeties remain entirely local to the equipment?
- Which operating modes are selected locally and which are selected by the supervisory system?
- Does the BAS receive actual equipment status, or only communication that the controller is online?
- Are alarms generated locally, at the BAS, or both?
- Which points are writable and which are read-only?
- What happens if the BAS network or gateway fails?
- What values remain stored locally after a controller restart?
- Who owns staging when multiple packaged units or plant components interact?
- Which trend data is available through the factory interface?

The engineer should avoid duplicating control authority unintentionally. If both a factory controller and the BAS attempt to regulate the same process without a clear hierarchy, the loops can conflict. A BAS reset command can also be ineffective if the factory controller applies tighter internal limits that are not documented in the project sequence.

Safeties require particular attention. A supervisory command should not casually bypass equipment protection that is intended to remain local or hardwired. The controls documents should distinguish normal supervisory logic from independent safety functions and identify the expected response when a local safety trips.

Network integration is another frequent source of ambiguity. A gateway may expose dozens or hundreds of points, but point availability is not the same as useful integration. The reviewer should confirm the exact points needed to execute and verify the accepted sequence. If a required status, alarm, setpoint, or mode is not available through the interface, the design may need another hardwired point, a different gateway configuration, or revised sequence logic.

Submittal review should compare the factory sequence with the project sequence. Questions to resolve before programming include:

- Are enable conditions compatible?
- Are minimum and maximum setpoints consistent?
- Are internal delays known?
- Are compressor, fan, pump, or burner stages controlled locally?
- Does the unit enforce minimum on/off times?
- What happens after power restoration?
- Which alarms latch locally?
- Can a BAS override persist after communication is restored?

Commissioning should then test the interface as a complete chain. A useful test does not stop at “the BAS sent the command.” It verifies that the factory controller accepted the command, the equipment entered the intended mode, the expected physical result occurred, and the BAS received meaningful proof or feedback.

A clearly defined factory-controls/BAS boundary reduces late programming disputes and prevents a common project failure: two individually reasonable control systems connected together without one coherent operating hierarchy.

4.25 POINT-TO-POINT VERIFICATION IS NECESSARY BUT NOT SUFFICIENT

During startup or commissioning, point-to-point verification confirms that the BAS point corresponds to the correct physical device and signal. Examples: command the damper and verify movement; change temperature and verify sensor response; start fan and verify proof; and open valve and verify actuator direction. This catches wiring, addressing, scaling, and installation errors. But point-to-point testing does not prove the sequence works. The system can have every point correct and still execute poor logic. Functional testing is therefore separate.

4.26 REVIEW A SEQUENCE USING “GIVEN — WHEN — THEN”

One useful engineering method is to rewrite each control requirement as a testable condition.

GIVEN:

the preconditions.

WHEN:

the initiating event.

THEN:

the expected result.

Example:

GIVEN:

The building is in occupied mode, supply fan is proven on, and outdoor-air conditions are suitable for economizer operation.

WHEN:

Zone cooling demand increases.

THEN:

The outside-air and return-air dampers modulate within defined limits to maintain the active supply-air-temperature setpoint while preserving minimum ventilation and appropriate building pressure.

The exact sequence may be more complex. The method forces the engineer to identify missing conditions and outcomes. It also makes commissioning easier because the sequence becomes testable.

4.27 INCLUDE FAILURE CASES IN THE SEQUENCE REVIEW

Engineers often test only normal operation mentally.

Failure review should ask:

- What if the sensor fails?
- What if communication fails?
- What if the fan fails?
- What if the pump fails?
- What if a damper sticks?
- What if the valve does not close?
- What if equipment does not prove?
- What if a safety trips?

- What if power returns after outage?
- What if one stage is unavailable?

The sequence does not need an elaborate response to every conceivable failure. It should address failures that are reasonably foreseeable and consequential.

4.28 MODULE 4 WORKED CASE — STATIC-PRESSURE RESET THAT SAVES ENERGY UNTIL ONE ZONE FAILS

A VAV system resets duct static pressure using zone damper requests. Normal logic reduces pressure when most dampers are partially closed and increases pressure when several dampers approach full open. This can be efficient. Now one zone airflow sensor fails low. The VAV controller believes airflow is insufficient. It drives the damper fully open and continuously requests more static pressure. The air handler responds by increasing fan pressure. Other dampers close to maintain their flows. Fan energy rises. Noise increases. The failed zone may still be uncomfortable.

A robust design can reduce the impact through: sensor-failure detection; request limits; ignoring clearly invalid zones; alarm logic; maximum static-pressure setpoint; and diagnostic trends.

The lesson is that demand-based resets need failure containment.

4.29 MODULE 4 WORKED CASE — CHILLED-WATER DP SENSOR MOVED DURING CONSTRUCTION

The design locates the differential-pressure sensor near a remote hydronic branch. During construction, controls conduit routing is difficult. The sensor is moved to the mechanical room. No sequence change is made. At startup, the pump maintains the original DP setpoint measured near the pumps. Remote valves struggle to obtain flow. The commissioning team raises the setpoint until remote flow is achieved. Now pressure at the pump discharge is much higher than intended. Control valves throughout the building operate near closed. The system works, but pumping energy and control stability are worse. The problem originated as a constructability change.

It became a controls problem. It was “solved” as a commissioning adjustment. This is exactly why design review, constructability, controls, and commissioning should not be treated as separate silos.

4.30 MODULE 4 WORKED CASE — THE ECONOMIZER THAT FIGHTS MECHANICAL COOLING

An air-handling unit is programmed so that outside-air dampers modulate open when outdoor temperature is below a fixed high limit. Mechanical cooling is also allowed whenever supply-air temperature rises above setpoint. On a cool humid day, the economizer opens. The added outside-air moisture increases coil load. Mechanical cooling operates heavily. The space temperature is controlled, but humidity rises and energy use is poor. The issue may involve the selected economizer control method, high-limit logic, humidity constraints, or system design. The engineering lesson is not that economizers are bad.

It is that control logic must reflect the actual psychrometric and climate conditions relevant to the system and the governing requirements.

4.31 MODULE 4 WORKED CASE — OPERATOR OVERRIDE BECOMES THE PERMANENT SEQUENCE

A commissioning technician forces a chilled-water pump to 70% speed to complete a test. The override is never removed. The pump remains at 70% for six months. The differential-pressure loop still displays its setpoint, but cannot control pump speed. Valves throttle against excessive pressure. The BAS shows no obvious alarm because the manual override status is buried in a point detail screen. A well-designed BAS would make the override visible and could time-limit or alarm persistent overrides. Commissioning should include an override-clearance check before turnover.

Module 4 Summary

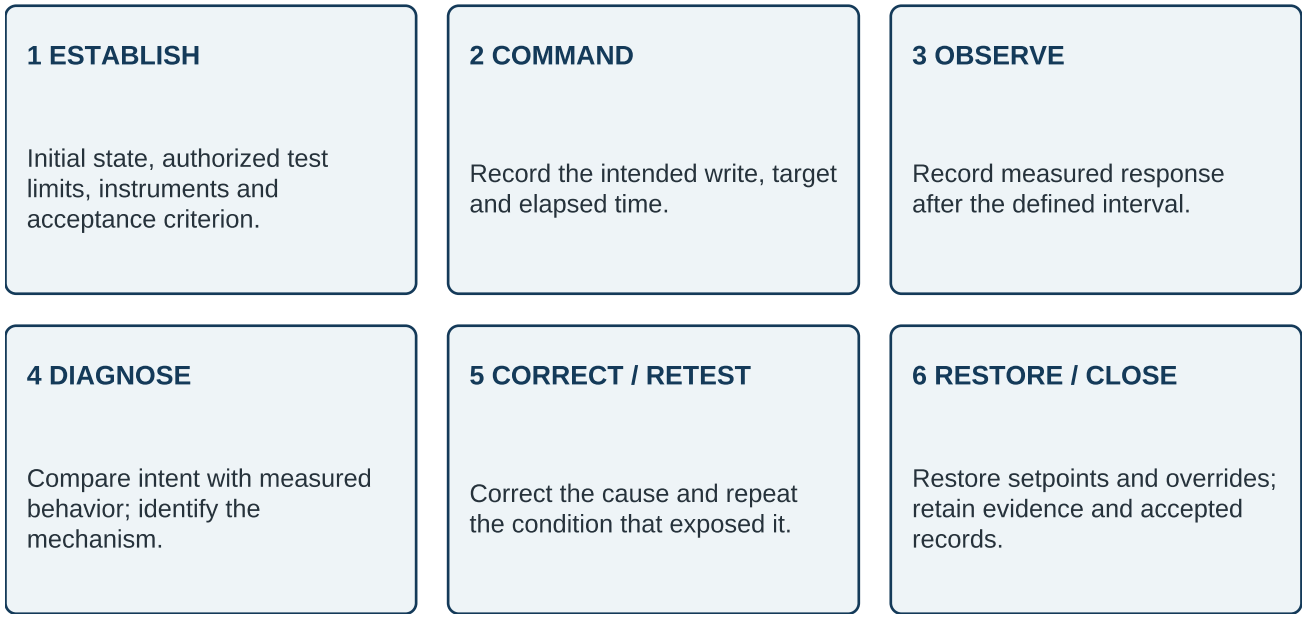
Controls translate engineering intent into building behavior.

A strong HVAC controls design: defines operating modes and transitions; distinguishes command from proof; treats sensor location and failure as engineering issues; defines actuator failure behavior; establishes setpoint purpose, range, and ownership; uses bounded reset strategies; recognizes interactions among nested control loops; defines occupied/unoccupied and recovery modes; engineers economizer and ventilation logic rather than relying on generic hardware; considers humidity where relevant; defines lead/lag and staging behavior; gives safeties clear priority; creates actionable alarms; specifies useful trend data; controls manual overrides; documents interfaces with other systems; considers network-loss behavior; reviews controls submittals against the sequence; separates point-to-point testing from functional performance testing; writes sequences in testable conditions; and includes consequential failure modes.

Module 5 uses commissioning to close the loop. The question changes from “Does the sequence sound correct?” to “Can the installed system demonstrate the required behavior under controlled test conditions?”

Functional-test evidence: command, response, diagnosis and retest

NIST Technical Note 2024 was published in February 2019. The study used real controller hardware with a simulated building. These are published controller-test records, not field trends from an occupied facility and not proof of compliance with a later Guideline 36 edition. The test record separates the intended command from the observed system response.



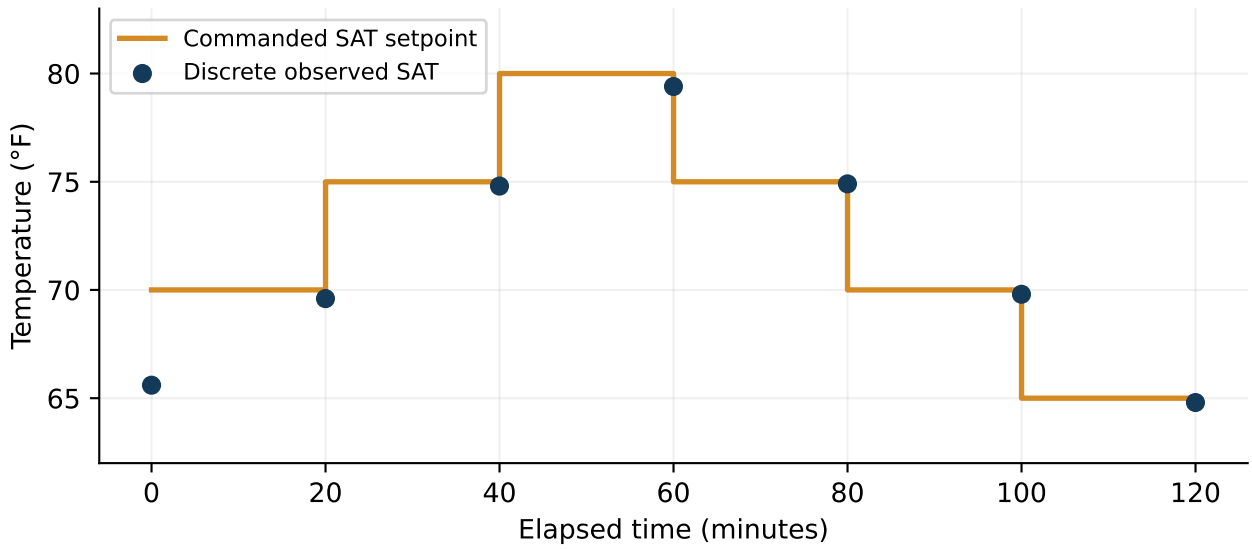
Plan the acceptance criterion before testing. A command or a point-to-point check does not prove the physical response; document the result, correct the mechanism, retest and restore normal control.

Supply-air-temperature test: read before the next write

Table 4: FPTM Results of the Supply Air Temperature Control Test

Event Description	Time Differential from Start (Minutes)	FPTM Value
Read SAT	+0	18.7 °C (65.6 °F)
Read and store SAT setpoint	+0	18.33 °C (65 °F)
Raise setpoint 3 °C (5 °F)	+0	**21.1 °C (70 °F)**
Read and verify SAT response	+20	20.9 °C (69.6 °F)
Raise setpoint 3 °C (5 °F)	+20	**23.9 °C (75 °F)**
Read and verify SAT response	+40	23.8 °C (74.8 °F)
Raise setpoint 3 °C (5 °F)	+40	**26.7 °C (80 °F)**
Read and verify SAT response	+60	26.3 °C (79.4 °F)
Lower setpoint 3 °C (5 °F)	+60	**23.9 °C (75 °F)**
Read and verify SAT response	+80	23.8 °C (74.9 °F)
Lower setpoint 3 °C (5 °F)	+80	**21.1 °C (70 °F)**
Read and verify SAT response	+100	21 °C (69.8 °F)
Lower setpoint 3 °C (5 °F)	+100	**18.3 °C (65 °F)**
Read and verify SAT response	+120	18.2 °C (64.8 °F)

NIST TN 2024, Table 4, printed page 8 (PDF page 13): original SAT commands, elapsed times and measured responses. Bold rows in the source identify write events.



NIST Table 4 values in °F. Gold steps are commanded setpoints; navy markers are discrete temperature readings, not a continuous trend. At a changeover time, the response reading precedes the next write.

COMMAND TIME, MIN	SETPOINT, °F	READ TIME, MIN	OBSERVED SAT, °F
0	70	20	69.6
20	75	40	74.8
40	80	60	79.4
60	75	80	74.9
80	70	100	69.8
100	65	120	64.8

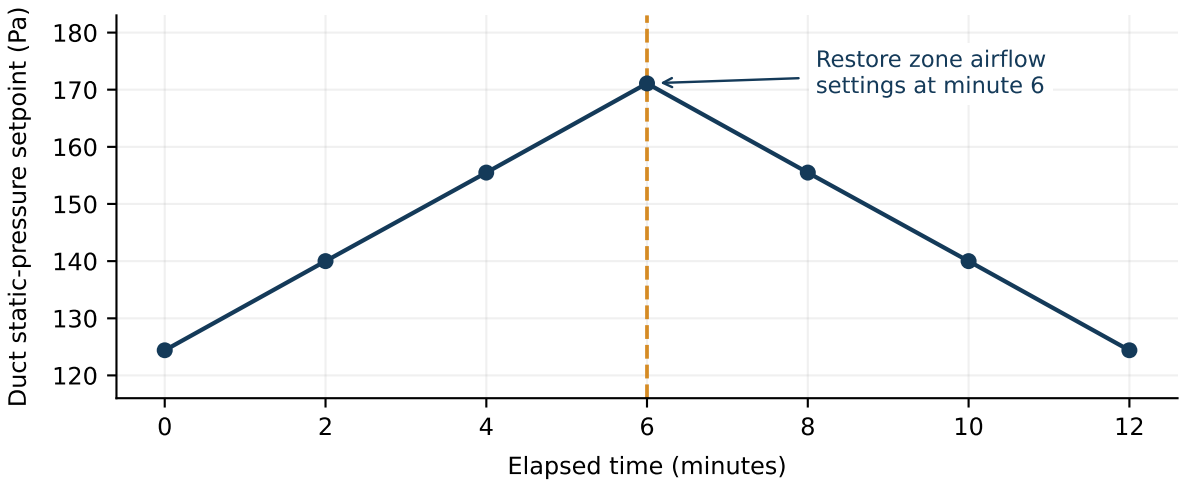
The initial measured SAT is 65.6°F and the stored initial setpoint is 65°F. Each listed response follows its command by 20 minutes. The largest absolute difference in these six paired endpoint readings is 0.6°F, which is a calculated observation rather than a pass/fail tolerance. A project test must establish allowable error, settling time, instrument requirements, permitted operating conditions and restoration steps before assigning a result.

Static-pressure reset: restore the test disturbance

Table 5: FPTM Results of the Trim & Respond Static Pressure Reset Logic

Event Description	Time Differential from Start (Minutes)	FPTM Value
Read AHU duct static pressure (DSP) setpoint	+0	124.4 Pa (0.5 inH_2O)
Read total air requests	+0	0
Read Zone 1 airflow setpoint	+0	47.2 L/s (100 cfm)
Read Zone 2 airflow setpoint	+0	47.2 L/s (100 cfm)
Triple Zone 1 airflow setpoint	+0	**141.6 L/s (300 cfm)**
Triple Zone 2 airflow setpoint	+0	**141.6 L/s (300 cfm)**
Read and verify increase in air requests	+2	5
Confirm setpoint response +15 Pa (0.06 inH_2O) at AHU	+2	140 Pa (0.5625 inH_2O)
Double Zone 1 airflow setpoint	+2	**283.2 L/s (600 cfm)**
Double Zone 2 airflow setpoint	+2	**283.2 L/s (600 cfm)**
Read total air requests at AHU	+4	6
Confirm setpoint response +15 Pa (0.06 inH_2O) at AHU	+4	155.5 Pa (0.625 inH_2O)
Double Zone 1 airflow setpoint	+4	**566.3 L/s (1200 cfm)**
Double Zone 2 airflow setpoint	+4	**566.3 L/s (1200 cfm)**
Confirm setpoint response +15 Pa (0.06 inH_2O) at AHU	+6	171.1 Pa (0.6875 inH_2O)
Set Zone 1 airflow setpoint to min value	+6	**47.2 L/s (100 cfm)**
Set Zone 2 airflow setpoint to min value	+6	**47.2 L/s (100 cfm)**
Confirm no air requests at AHU	+8	0
Confirm setpoint response -12.4 Pa (-.05 inH_2O) at AHU	+8	155.5 Pa (0.625 inH_2O)
Confirm setpoint response -12.4 Pa (-0.05 inH_2O) at AHU	+10	140 Pa (0.5625 inH_2O)
Confirm setpoint response -12.4 Pa (-0.05 inH_2O) at AHU	+12	124.4 Pa (0.5 inH_2O)

NIST TN 2024, Table 5, printed page 9 (PDF page 14): original forced airflow demands, duct static-pressure setpoint responses and restoration of zone settings.



Recorded pressure-setpoint endpoints from NIST Table 5. Zone airflow settings are restored at minute 6; subsequent observations show the setpoint returning to its initial value. Connecting lines guide reading between recorded events.

The plotted Pa values reproduce the absolute setpoints as printed. Table 5's decrement labels and Pa endpoints are not fully consistent. Verify programmed increments and units against the governing sequence rather than using this historical table as a project acceptance procedure.

TEST PHASE	RECORDED RESPONSE	ENGINEERING INTERPRETATION
Initial state, minute 0	0 requests; 124.4 Pa pressure setpoint	Preserve initial settings and confirm the baseline.
Increase zone airflow settings	140 Pa at minute 2; 155.5 Pa at minute 4; 171.1 Pa at minute 6	Imposed demand produces requests and a responding pressure setpoint.
Restore both zones at minute 6	0 requests at minute 8; pressure setpoint returns to 124.4 Pa by minute 12	Test recovery and remove imposed settings, not only the increasing-demand response.

Diagnosis and retest: verify the control input path

NIST also reported that some commanded BACnet values initially did not affect the controller as expected. The control logic was using internal variables that were not coupled to the intended BACnet object inputs. After those inputs were connected to the control logic, the controller responded as expected. A visible BAS value therefore needs an end-to-end check: identify the command, verify which variable actually drives the logic, confirm the physical response and repeat the failed condition after correction.

> **Project application.** Specify the initial condition, authorized write, expected response, acceptance limit, restoration method and evidence to retain. If a response fails, record the discrepancy and investigate its mechanism. A corrected screen value alone does not close the issue; repeat the complete functional test and verify normal control after overrides are removed.

Primary source:NIST Technical Note 2024, Tables 4–5 and implementation findings

Commissioning, Functional Performance & Turnover



Contextual photograph: Professional field-verification context. Commissioning requires defined procedures and measured system evidence.

5.1 COMMISSIONING IS A PROCESS FOR VERIFYING PERFORMANCE, NOT A FINAL INSPECTION

COMMISSIONING STAGE	EVIDENCE TO PRESERVE
Requirement / design basis	Owner need and engineering response.
Design / sequence / selection	Specified behavior and actual equipment.
Installation / prefunctional readiness	Field condition and readiness for safe testing.
Functional test	Demonstrated integrated behavior.
Issue / correction / retest	Deficiency closure supported by evidence.
Turnover	Accepted sequence, setpoints, records and training.

Commissioning is often misunderstood as an activity that occurs near the end of construction when a commissioning provider arrives, tests equipment, and creates a deficiency list. That view is too narrow.

ANSI/ASHRAE/IES Standard 202-2024 establishes a commissioning process for new buildings and new systems that extends from project planning through occupancy and operation. ASHRAE Guideline 1.1-2025 adds HVAC&R-specific technical detail.

The engineering value of commissioning comes from traceability.

The process creates a line from:

owner requirements → design basis → construction documents → submittals → installation → startup → functional testing → training → operations. A deficiency can occur anywhere along that line. If commissioning begins only after equipment startup, the project loses the opportunity to catch design and coordination problems before they become installed conditions.

5.2 START WITH THE OWNER'S PROJECT REQUIREMENTS

Commissioning needs a target. The Owner's Project Requirements, commonly abbreviated OPR, describe the owner's functional expectations and criteria.

Depending on project scope, the OPR may address: occupancy; temperature; humidity; ventilation; indoor environmental quality; operating schedules; energy goals; resilience; and redundancy. Additional considerations include maintainability; serviceability; training; controls; metering; documentation; future flexibility; and testing expectations.

The OPR should be specific enough to guide design decisions. "Provide an energy-efficient HVAC system" is too vague to test. "Provide normal occupied HVAC operation from 7:00 a.m. to 7:00 p.m., allow tenant after-hours overrides by zone, and restore automatic operation after the override period" is testable. The mechanical engineer should understand the OPR because the design is one technical response to those requirements.

5.3 THE BASIS OF DESIGN EXPLAINS HOW THE ENGINEER INTENDS TO MEET THE REQUIREMENTS

The Basis of Design, often abbreviated BOD, documents the design concepts, assumptions, calculations, system selections, and decisions used to satisfy the OPR.

For HVAC systems, the BOD can include: design conditions; load assumptions; ventilation approach; system types; zoning; equipment-selection basis; and redundancy. Additional considerations include energy strategy; control concepts; filtration; humidity control; acoustics; maintainability; and applicable codes/standards.

The BOD is valuable during commissioning because it explains why the system is designed the way it is.

If a functional test identifies unexpected behavior, the commissioning team can distinguish among:

- design intent is correct but implementation is wrong;
- design intent is unclear;
- design intent no longer matches owner requirements;
- design itself requires correction.

Without a BOD, the team may only compare the installation to the drawings without knowing whether the drawings meet the intended function.

5.4 COMMISSIONING DESIGN REVIEW IS DIFFERENT FROM ORDINARY PEER REVIEW

A commissioning design review focuses on whether the design can be verified and operated.

It may ask:

- Are OPR requirements represented in the design?
- Are sequences complete?
- Can required modes be tested?
- Are sensors and BAS points sufficient?
- Are test ports provided?
- Can equipment be isolated?
- Are balancing devices included?
- Are commissioning responsibilities defined?
- Are startup requirements clear?
- Is access adequate?
- Are controls interfaces defined?
- Can performance be trended?

- Are training/documentation requirements specified?

A traditional design peer review may focus more heavily on sizing, technical compliance, and design quality.

The reviews overlap, but the commissioning perspective asks an additional question:

“How will we prove this requirement after the system is installed?”

That question often exposes missing instrumentation or incomplete sequences.

5.5 COMMISSIONING SPECIFICATIONS SHOULD ALLOCATE RESPONSIBILITY

Commissioning requires participation by multiple parties.

Potential participants include: owner; design team; commissioning provider; mechanical contractor; controls contractor; TAB contractor; equipment manufacturers; electrical contractor; facility staff; and specialty trades.

The project documents should define responsibilities for: submittals; startup; checklists; documentation; testing; trend setup; deficiency correction; retesting; training; O&M manuals; systems manual; and seasonal tests.

Ambiguous responsibility creates delay. For example, if the commissioning provider requires a trend log but the controls contractor did not include trend setup in scope, the project may enter dispute rather than testing. The engineer should help ensure that necessary commissioning activities are contractually visible.

5.6 SUBMITTAL REVIEW IS A COMMISSIONING CONTROL POINT

Commissioning review of submittals can identify changes that affect performance or testing.

Examples: a fan has different turndown than assumed; a chiller requires different minimum flow; a control valve has different closeoff pressure; a rooftop unit has factory controls that conflict with BAS sequence; a VFD lacks a required interface; a sensor range differs; an air handler has different filter pressure drop; and a pump selection shifts operating point.

The design engineer’s submittal review remains governed by the contract. The commissioning process adds a functional perspective. Changes should be reconciled with the BOD, sequence, testing procedure, and controls points.

5.7 PREFUNCTIONAL VERIFICATION CONFIRMS READINESS FOR FUNCTIONAL TESTING

Before functional testing, the system should be physically ready.

Prefunctional verification can include confirmation that:

- equipment is installed;
- startup is complete;
- filters are installed;
- belts/couplings are adjusted;
- valves are open as intended;
- strainers are clean;
- piping is flushed;
- sensors are installed;
- actuators operate;
- control points are mapped;
- safeties are active;
- TAB is complete to the required stage;
- labels are present;
- access is available;
- documentation exists.

The exact checklist depends on the system. The important principle is that functional testing should not be used as a substitute for basic installation quality control. If the air handler has not been started correctly, functional testing of its economizer sequence is premature.

5.8 STARTUP IS NOT COMMISSIONING

Manufacturer startup confirms that equipment can operate and often protects warranty. Commissioning asks whether the equipment operates correctly as part of the building system. A chiller can pass manufacturer startup and still be staged poorly. A VFD can start a fan while the static-pressure sequence is wrong. A rooftop unit can cool while ventilation logic is incorrect. A boiler can fire while lead/lag operation is incomplete. A BAS point can read correctly while the failure response is wrong. Startup and commissioning are complementary. Neither replaces the other.

5.9 TAB IS PART OF THE EVIDENCE BASE

TAB establishes important measured performance. Commissioning should use the final TAB report rather than treat it as an unrelated deliverable. The commissioning team may verify selected measurements, investigate anomalies, or use TAB data to establish functional-test conditions.

Important questions include:

- Was TAB performed in the intended control mode?
- Were setpoints temporarily forced?
- Were filters clean?
- Were control valves or dampers positioned manually?
- Was diversity represented?
- Are fan/pump speeds documented?
- Are unresolved exceptions listed?

A TAB report can show that design flow was achieved, but commissioning should determine whether the automatic system can maintain useful performance afterward.

5.10 FUNCTIONAL PERFORMANCE TESTING SHOULD TEST THE SEQUENCE, NOT JUST COMPONENTS

A functional performance test challenges the system under defined conditions and verifies expected response.

For an air handler, tests may address:

- occupied enable;
- unoccupied shutdown;
- fan proof failure;
- supply-air temperature control;
- static-pressure control;
- reset logic;
- economizer operation;
- minimum ventilation;
- freeze protection;
- smoke shutdown interface;
- alarm generation;
- sensor failure;
- recovery after power loss.

For a hydronic system: pump enable; lead/lag rotation; differential-pressure control; reset; equipment staging; low-flow protection; failure of lead pump; temperature reset; alarm; and sensor failure.

The test should reference the sequence. If the test procedure cannot determine the expected result because the sequence is ambiguous, that ambiguity is a design deficiency.

FUNCTIONAL-TEST SAMPLING, REPEATABILITY & EXPANSION

Large HVAC systems may contain dozens or hundreds of similar devices. Functional testing therefore needs a defensible strategy for deciding what is tested individually, what can be sampled, and what happens when a sampled device fails.

The course does not prescribe a universal sampling percentage. The appropriate scope depends on project requirements, system criticality, contractual commissioning requirements, device population, control architecture, observed quality, and consequence of failure. The important engineering principle is that a sample should represent the population it is being used to judge.

For repeated terminal equipment, a representative sample may deliberately include different: equipment sizes or capacities; orientations or physical locations; exposure conditions, such as perimeter and interior zones; controller or firmware types where they differ; installation crews or project phases; critical and noncritical spaces; upstream system branches; and operating modes.

A sample made only from the easiest devices to reach is convenient but may not be representative.

The test procedure should also define repeatability. If a sequence is expected to behave the same way each time a condition occurs, the test should produce enough evidence to show that the result is stable rather than accidental. A single successful transition may not be persuasive when the observed problem is intermittent. Trend data can be useful when the behavior depends on time, load, or repeated cycling.

Sampling becomes especially important when a failure is found. A failed sample should trigger a deliberate expansion decision rather than an automatic assumption that the defect is isolated. The team should ask whether the cause could be systemic.

Examples of potentially systemic causes include: a programming template used across many controllers; an incorrect point mapping repeated across a device family; a sensor installed from the same detail in multiple locations; a control-valve selection repeated across similar coils; a balancing or startup procedure applied consistently but incorrectly; and a submittal interpretation that affected an entire equipment type.

If the failure mechanism is common to the population, testing only the originally failed device after correction provides weak evidence. The appropriate response may be to expand the sample, inspect the common template or installation detail, correct all affected devices, and retest enough of the population to demonstrate that the systemic cause has been removed.

Conversely, not every failure requires full-population testing. If the cause is demonstrably local—for example, one damaged actuator or one miswired sensor—and broader review shows no common mechanism, a focused correction and retest may be appropriate.

A good commissioning record should state:

- which devices or conditions were tested;
- why they were selected;
- the expected result;
- the observed result;
- whether a failure appeared local or systemic;
- whether the sample was expanded;
- what was corrected;
- what was retested.

This approach makes sampling an engineering evidence strategy rather than a shortcut. It also gives the owner a clearer basis for understanding what the commissioning results do—and do not—demonstrate about the full installed system.

5.11 TEST CONDITIONS SHOULD BE CREATED INTENTIONALLY

Waiting for natural conditions can delay testing. Commissioning often requires simulation or overrides to create test conditions. Examples: simulate an outdoor-air temperature; force zone demand; change setpoint; disable equipment; simulate a sensor failure; command a valve; and change occupancy mode. Overrides should be controlled, documented, and removed.

The test procedure should identify:

- initial condition;
- simulated condition;
- expected response;
- acceptance criterion;
- restoration step.

This reduces the risk that testing leaves the system in an abnormal state.

5.12 ACCEPTANCE CRITERIA SHOULD BE DEFINED BEFORE THE TEST

A statement such as “verify the fan operates correctly” is weak. A useful test defines measurable or observable criteria.

Examples: fan starts within the specified delay after enable; proof is received; control loop stabilizes within the allowed range; alarm occurs after the defined failure delay; standby pump starts after lead failure; damper moves to the required failure position; and setpoint resets within defined bounds.

Not every criterion needs a numerical tolerance. But the test team should know what constitutes pass or fail.

5.13 FUNCTIONAL TESTING SHOULD INCLUDE TRANSITIONS

Steady-state tests are easier. Transitions often reveal defects. Examples: occupied to unoccupied; warm-up to occupied; economizer to mechanical cooling; one chiller to two; lead pump failure to standby; dehumidification to normal cooling; and loss and restoration of power. Transitions can expose: delays; conflicting commands; integrator windup; incorrect priorities; unstable loops; missing resets; and alarm floods. A commissioning plan should intentionally test critical transitions.

5.14 FAILURE-MODE TESTING SHOULD BE PROPORTIONAL TO CONSEQUENCE

Not every component failure needs to be simulated. High-consequence or likely failures deserve attention. Examples: loss of fan proof; failed temperature sensor; failed differential-pressure sensor; stuck damper; lead pump failure; loss of communication; high condensate; freeze-stat trip; and alarm failure. The test should confirm safe fallback and operator notification where required. Failure testing also checks whether the sequence actually contains the intended logic.

5.15 TREND-BASED COMMISSIONING EXTENDS THE TEST WINDOW

A functional test may last minutes. Some problems occur over hours or days. Trend data can verify: morning recovery; night shutdown; load transitions; reset strategies; staging; humidity; pressure; simultaneous heating/cooling; and persistent overrides. Trend review should compare related points.

For example: supply-air temperature and setpoint; fan speed and static pressure; static setpoint and VAV damper requests; chilled-water DP and pump speed; valve positions and DP reset; and zone temperature, setpoint, airflow, and reheat.

Patterns are often more informative than individual values.

5.16 DEFICIENCY MANAGEMENT SHOULD PRESERVE TECHNICAL TRACEABILITY

A commissioning issue log should identify:

- issue;
- location/system;
- observed condition;
- requirement or expected behavior;
- responsible party;
- status;
- corrective action;

- retest result.

A useful issue description avoids blame and focuses on evidence.

Example:

“During AHU-2 economizer test, outdoor-air damper opened to 100% but return-air damper remained at 80% open. Mixed-air temperature did not approach the commanded setpoint. Sequence requires coordinated modulation. Controls contractor to verify damper mapping and sequence logic. Retest required.”

This is more useful than:

“Economizer failed.”

5.17 CORRECTIVE ACTION SHOULD ADDRESS CAUSE

Commissioning can become repetitive if teams correct symptoms without identifying causes.

For example:

Symptom:

zone is warm.

Correction:

increase airflow. If the underlying problem is a sensor location, solar load, duct restriction, or sequence, increasing airflow may create new issues.

A good deficiency process asks:

- What caused the observed failure?
- Is this isolated or systemic?
- Does the correction affect another system?
- Does the design document need revision?
- Does the sequence need revision?
- Does similar equipment require inspection?

A repeated deficiency may indicate a process problem rather than multiple isolated failures.

5.18 RETESTING IS PART OF CLOSURE

A written response saying “corrected” is not always enough. If an issue involved functional behavior, the corrected condition should normally be verified. Retest can be: full; partial; trend-based; and document-based. depending on the issue. The commissioning record should distinguish: correction reported; correction observed; and correction functionally verified.

5.19 SEASONAL AND DEFERRED TESTING SHOULD BE PLANNED

Some HVAC functions cannot be fully tested under current weather or load. Examples: heating during summer; cooling during winter; economizer conditions; heat-rejection capacity; and low-ambient refrigeration behavior. The project should identify deferred tests and responsibility for completion. A deficiency list should not silently disappear at substantial completion because the necessary season has not occurred. Seasonal testing can also verify that setpoints and schedules have not drifted since initial turnover.

5.20 COMMISSIONING SHOULD VERIFY DOCUMENTATION AS WELL AS OPERATION

The owner needs accurate records.

Turnover documents can include: final sequences; setpoints; controls diagrams; points lists; alarm lists; trend lists; and equipment schedules. Additional considerations include O&M manuals; TAB reports; commissioning reports; as-built drawings; training records; warranties; and contact information.

A system may operate well at turnover but become difficult to maintain if documentation is incomplete. The final controls sequence is especially important. If field programming changed from the design sequence, the owner should receive the actual accepted sequence.

5.21 TRAINING SHOULD BE SYSTEM-BASED, NOT ONLY EQUIPMENT-BASED

Manufacturer training often focuses on equipment. Owner staff also need to understand the system. Useful system training includes: operating modes; schedules; setpoints; alarms; overrides; failure responses; seasonal changes; maintenance dependencies; trend use; and reset strategies. Operators should know why the system behaves the way it does. Otherwise, a well-designed reset strategy may be disabled because the operator interprets changing setpoints as malfunction. Training is therefore part of performance persistence.

5.22 THE SYSTEMS MANUAL SUPPORTS LONG-TERM OPERATION

Commissioning frameworks emphasize organized system information. A systems manual can bring together: OPR; BOD; system descriptions; sequences; setpoints; operating procedures; commissioning results; maintenance information; and training. The exact format varies. The engineering value is that future staff can understand intended operation. This is especially important after staff turnover. Buildings often lose performance because institutional knowledge leaves.

5.23 PERSISTENCE REQUIRES POST-OCCUPANCY ATTENTION

A commissioned system can drift. Causes include: setpoint changes; overrides; sensor drift; schedule changes; equipment degradation; occupant modifications; deferred maintenance; and control updates. Ongoing monitoring, periodic reviews, analytics, or recommissioning can preserve performance. The level of effort should match the building. A small building may need periodic checks. A large complex facility may benefit from continuous monitoring. The design should at least provide enough measurement and documentation to make future verification possible.

5.24 MODULE 5 WORKED CASE — THE AIR HANDLER PASSES STARTUP BUT FAILS FUNCTIONAL TEST

An air handler has completed manufacturer startup. The fan operates. Cooling works. The BAS is online. During functional testing, the commissioning provider simulates increasing zone cooling demand.

Expected:

duct-static setpoint rises in response to zone damper requests.

Observed:

fan speed increases immediately to 100%. The static-pressure setpoint does not change. Investigation finds that the controls contractor programmed fan speed directly from the number of zone requests rather than using requests to reset the pressure setpoint. The fan can deliver airflow. The system is not operating according to design intent. Startup could not identify the issue because the fan itself works. Point-to-point testing could not identify the issue because all points are correct. Only functional testing exposes the logic difference. The correction requires: revise programming; verify setpoint limits; trend requests; and repeat the test.

5.25 MODULE 5 WORKED CASE — THE PUMP FAILOVER THAT WORKS ONLY ON SCREEN

A chilled-water system has two pumps. The graphics show Pump 1 as lead and Pump 2 as standby. The sequence says the standby pump starts on lead failure.

During testing:

1. Pump 1 is commanded on. 2. proof is received. 3. the proof signal is simulated failed.

Expected:

Pump 1 stops, Pump 2 starts, alarm occurs.

Observed:

Pump 2 receives a start command but does not run. Investigation finds that the Pump 2 hand-off-auto (HOA) switch is in OFF after maintenance. This is not a programming defect. The sequence issued the correct command. The failure exposes an operational readiness issue. The commissioning result should still be treated as a failed functional test until the standby function is restored and verified.

5.26 MODULE 5 WORKED CASE — THE VENTILATION SYSTEM MEETS DESIGN FLOW ONLY DURING TAB

TAB reports correct outdoor airflow. During commissioning, the building is tested at low supply airflow. Outdoor airflow falls substantially below the intended minimum. Investigation finds that TAB established minimum damper position at design supply flow. The sequence uses that fixed position at all fan speeds. At reduced fan speed, the same damper position produces less outdoor air. The design ventilation quantity existed in the TAB report. It did not persist across operating modes.

Corrective options depend on system design and governing requirements, but the key lesson is clear:

A balancing condition is not a control strategy.

5.27 MODULE 5 WORKED CASE — THE OWNER CANNOT MAINTAIN THE ACCEPTED SYSTEM

A new building receives sophisticated optimized controls. Commissioning verifies operation. Six months later, performance deteriorates. The owner reports that staff disabled reset logic because they did not understand changing setpoints. The issue is not necessarily a bad design. It is a turnover failure. Commissioning should confirm not only system operation but sufficient training and documentation for the actual operations team. Technical sophistication without operational transfer is not durable performance.

Module 5 Summary

Commissioning closes the loop between engineering intent and measured building behavior.

A strong commissioning process: traces requirements through the basis of design; reviews design for verifiability; allocates responsibilities; reconciles submittals; confirms prefunctional readiness; distinguishes startup from commissioning; uses TAB as evidence; tests the actual sequence; intentionally creates test conditions; defines acceptance criteria; tests transitions and consequential failures; uses trend data for longer-term behavior; maintains a technical issue log; corrects causes rather than symptoms; retests corrected conditions; plans seasonal/deferred tests; verifies final documentation; trains operators in system behavior; preserves the accepted sequence and setpoints; and supports future performance persistence.

Module 6 integrates all five prior modules into realistic engineering decisions where design, constructability, distribution, controls, and commissioning overlap.

MODULE 6 | 30 MINUTES

Integrated HVAC Case Studies & Engineering Decision Practice

COMFORT Capacity met, but zones remain warm.	**HYDRONICS** Differential pressure and valve hunting.
ACCESS Equipment cannot be serviced or replaced.	**CONTROLS** Commands appear correct; response fails.
COMMISSIONING Failure mode or transition is not proven.	**CLOSURE** Correct the mechanism and retest the condition.

Integrated HVAC cases use the same evidence-led reasoning across comfort, hydronics, access, control response, commissioning and closure.

6.1 WHY INTEGRATED CASES MATTER

Real HVAC problems rarely announce which discipline owns them. A comfort complaint may be caused by load assumptions, duct resistance, diffuser layout, VAV minimums, sensor placement, controls, balancing, envelope changes, or occupant behavior. A pumping problem may be caused by valve sizing, differential-pressure sensor location, plant staging, piping changes, pump minimum speed, or control logic. The practicing engineer therefore needs a method for separating symptoms from mechanisms.

The cases in this module use the same sequence repeatedly:

1. Define the observed condition. 2. Confirm the measurement. 3. Reconstruct design intent. 4. Check the physical installation. 5. Check distribution performance. 6. Check controls. 7. Check commissioning evidence. 8. Identify the most likely mechanism. 9. Select corrective action. 10. Verify the correction. This structure prevents premature conclusions.

CASE 1 — THE AIR HANDLER MEETS CAPACITY BUT THE BUILDING HAS HOT ZONES

Project condition:

A three-story office building uses one VAV air-handling unit. The air handler is scheduled for 30,000 cfm. TAB reports 30,200 cfm total supply airflow. Cooling capacity meets the scheduled condition. During hot afternoons, several west and south perimeter zones rise above setpoint. The initial reaction is that the air handler is undersized. Step 1 — Confirm the complaint. Trend data shows affected zones rise 2–3°F above setpoint for approximately two hours. The complaints are real and repeatable. Step 2 — Confirm measurement. Space sensors are compared with calibrated instruments. Two sensors are accurate. One sensor reads approximately 1.5°F low.

The sensor error explains one zone but not the others. Step 3 — Reconstruct design intent. The design documents show: VAV system; supply-air temperature setpoint of 55°F at design; static-pressure reset; perimeter reheat; and scheduled maximum airflows based on design cooling loads. Step 4 — Check installation. Coordination drawings show the perimeter duct branch received two large offsets to avoid structure. A flexible duct run to one diffuser exceeds the design detail. No major equipment defect is found. Step 5 — Check distribution.

At peak demand: supply fan is near 95% speed; static pressure meets setpoint at the sensor; upstream VAV dampers are partly closed; affected perimeter VAV dampers are 100% open; and affected boxes cannot achieve scheduled maximum airflow.

This indicates the problem is not total air-handler capacity. The air is not being distributed where needed. Step 6 — Check controls. Static pressure is sensed upstream of the added branch resistance. The reset logic believes adequate pressure exists. The system cannot recognize the remote branch deficiency. Step 7 — Review commissioning evidence. Original commissioning occurred before final tenant buildout. Functional tests did not represent the final branch configuration or tenant load.

Engineering conclusion:

The dominant mechanism is a distribution/control-location problem, not inadequate air-handler cooling capacity.

Possible corrective actions: evaluate branch resistance and duct modification; relocate or supplement static-pressure sensing; revise static-pressure reset logic; correct the inaccurate zone sensor; correct excessive flexible duct; and verify terminal maximum airflow and diffuser performance.

Verification:

After corrections, trend: zone temperature; terminal airflow; damper position; fan speed; static pressure; and static setpoint. The case demonstrates why total airflow and equipment capacity are insufficient measures of system performance.

CASE 2 — CHILLED-WATER PLANT HAS LOW DELTA-T AND HIGH PUMP ENERGY

Project condition:

A variable-flow chilled-water system serves several air handlers. The plant was designed for a 14°F temperature difference. During moderate load, measured delta-T is commonly 7–9°F. Pumps operate faster than expected. Operators believe the coils are undersized. Step 1 — Confirm measurement. Supply and return temperature sensors are checked. One sensor has minor calibration error but cannot explain the entire condition. Plant flow measurement is verified within acceptable accuracy. Step 2 — Review load. Building cooling load is moderate. The low delta-T is not simply a near-zero-load condition. Step 3 — Review coil performance.

Selected coils are appropriate at design conditions. Several control valves are operating near closed. Step 4 — Review hydraulic system. Differential-pressure setpoint is fixed. The sensor is located near the plant. The setpoint was increased during startup because remote coils initially lacked flow. Step 5 — Review field history. The original DP sensor was intended for a remote location but moved during construction. The sequence was not revised. Step 6 — Review controls. Pumps maintain the elevated fixed DP. There is no valve-position-based reset. Many valves throttle against excessive pressure. Some zones show unstable valve movement.

Engineering conclusion:

The low delta-T is a system symptom. High differential pressure and poor valve operating range are contributing to excess flow. The original sensor relocation changed the control basis.

Potential correction: evaluate return of sensing to an appropriate remote location; establish bounded DP reset based on actual system demand; review control-valve sizing/authority at problematic coils; verify minimum equipment-flow constraints; and retune loops after hydraulic conditions are corrected.

Verification:

Trend: plant flow; chilled-water supply/return temperature; pump speed; DP/setpoint; representative valve positions; and load. The objective is not merely to force 14°F at all times. The objective is to restore controllable flow and improve system behavior across the load range.

CASE 3 — EQUIPMENT IS SIZED CORRECTLY BUT CANNOT BE MAINTAINED

Project condition:

A packaged rooftop air handler serves a large retail space. The unit meets capacity, efficiency, and electrical requirements. During the first major service, the owner discovers that a large fan assembly cannot be removed because a parapet and screen wall block the manufacturer's service path. The unit can be serviced for filters and belts but not for major repair. How did the problem survive design?

Design review:

The equipment schedule referenced manufacturer service clearances, but the roof plan showed only unit footprint.

Architectural review:

Screen walls were added late.

Coordination:

The model checked equipment and screen-wall geometry for physical clash but did not model removal path.

Submittal review:

The selected unit's service drawing showed the required removal zone. No one reconciled it with the final screen wall.

Commissioning:

Functional tests proved the unit operated correctly. They did not test future replacement access.

Engineering conclusion:

The system is functionally commissioned but lifecycle constructability is deficient. Potential resolutions may include: removable screen-wall panels; alternate service procedure approved by manufacturer; rigging provisions; and architectural modification.

The broader corrective action is process-based:

Future reviews should separately track: routine service; major repair; and full replacement. This case shows why commissioning does not eliminate the need for constructability review. Commissioning verifies function. It does not automatically prove lifecycle access.

CASE 4 — ECONOMIZER, MECHANICAL COOLING & VENTILATION CONTROL CONFLICT

Project condition:

A VAV air handler includes outdoor-air control and economizer operation. Occupants report high humidity during mild weather. Trend data shows: outdoor-air damper frequently near full open; cooling valve also heavily open; supply-air temperature maintained; return-air humidity increasing; and zone temperatures generally acceptable. Step 1 — Review design intent. The sequence states that economizer operation is enabled below an outdoor-air temperature threshold. Mechanical cooling remains available to maintain supply-air temperature. Minimum ventilation is controlled by outdoor-air damper minimum position. Step 2 — Review climate/psychrometrics.

Mild outdoor dry-bulb temperature does not necessarily indicate low moisture content. The simple temperature high limit can enable large outdoor-air quantities during humid conditions. Step 3 — Review outdoor-air measurement. The system does not measure outdoor airflow directly. Minimum position was established during TAB at design fan speed. Step 4 — Review variable-flow operation. At low fan speed, damper position does not represent the same airflow. During economizer, the return damper does not coordinate properly. Step 5 — Review commissioning. Economizer testing occurred on a dry day. Humidity behavior under humid mild conditions was not tested.

Engineering conclusion:

The issue involves both sequence design and ventilation measurement.

Corrective action requires project-specific evaluation of: economizer high-limit method; humidity constraints; damper coordination; minimum ventilation strategy; measurement; and supply-air-temperature/dehumidification strategy.

Verification should include trend data under representative humid conditions. The case shows why a control sequence can maintain temperature while still failing the building's broader environmental requirements.

CASE 5 — RENOVATION PHASING CREATES AN UNDESIGNED HVAC SYSTEM

Project condition:

A hospital-adjacent medical office renovation occurs in three phases. The final design replaces two air handlers with one new unit. Construction must keep half the floor occupied. Temporary duct connections are developed in the field. During Phase 2, occupants complain of odors and pressure imbalance. The permanent design is not yet complete. Step 1 — Identify the temporary system.

During the phase: one existing air handler remains; portions of return duct are removed; temporary supply duct feeds occupied rooms; several doors are used as pressure boundaries; and BAS zones do not correspond to the temporary layout.

Step 2 — Review temporary load/ventilation. Occupancy remains substantial. Temporary outside-air quantity was not calculated. The existing unit is capable of cooling the area, but ventilation and pressure relationships were not re-evaluated. Step 3 — Review controls. The BAS still uses pre-renovation occupancy schedules and sensors. Several sensors are now located in construction zones. Step 4 — Review physical pathways. Return air can travel from construction space toward occupied areas. Temporary barriers are not coordinated with HVAC pressure.

Engineering conclusion:

Construction phasing created a temporary mechanical system that requires engineering design. The issue is not simply a contractor means-and-methods problem because occupied-building environmental performance depends on the temporary airflow path.

Potential corrective action: define temporary supply/return paths; calculate required outdoor air; relocate temporary sensors; establish pressure relationships; revise temporary controls; coordinate barriers and doors; define monitoring; and recommission each phase.

This case demonstrates that temporary HVAC states can deserve the same engineering rigor as permanent systems when consequences are meaningful.

CHOOSING THE CORRECT CORRECTION PATH

Once the mechanism is understood, the next engineering task is to choose the correction that addresses the cause without creating a new problem. That decision is often more important than identifying the symptom.

A useful correction-path framework separates six types of action:

Design clarification.

Use clarification when the accepted design intent is technically sound but the documents do not communicate it clearly enough for implementation or testing. Examples include an ambiguous control transition, an incomplete sensor-location note, or a submittal question that can be resolved without changing the underlying design. The clarification should become part of the controlled project record so the same ambiguity does not reappear during commissioning or future service.

Design revision.

Use redesign when the accepted design itself cannot reliably achieve the required performance. Examples include a distribution path with inadequate pressure capability, a zoning concept that combines incompatible loads, an equipment selection that cannot operate over the required range, or a control concept that depends on information the system cannot measure. A design revision should be evaluated for downstream effects on electrical service, structural support, space, acoustics, controls, TAB, commissioning, cost, schedule, and other affected disciplines.

Field correction.

Use a field correction when the design intent is adequate but the installed condition does not conform or cannot perform as required. Examples include a reversed valve, obstructed duct, incorrectly located sensor, inaccessible actuator, missing balancing device, or improper condensate trap. The correction should restore the intended condition rather than create an undocumented alternate design.

Controls revision.

Use a programming or sequence revision when the physical system is adequate but the implemented logic does not match the accepted operating intent. A controls change should identify the affected mode, setpoint, reset, alarm, interlock, safety, or failure response; update the accepted sequence where necessary; and be functionally retested. A programmer's field change should not become the permanent operating standard solely because it appeared to solve a complaint.

Operational or maintenance correction.

Use this path when the accepted system is fundamentally capable but operation has drifted from the intended condition. Common examples include persistent manual overrides, altered schedules, dirty filters or strainers, failed actuators, sensor drift, disabled alarms, or setpoints changed without engineering review. Correcting the operating condition should include restoring automatic control and confirming that the original sequence remains appropriate.

Owner decision.

Some conditions involve a tradeoff rather than a single technical answer. The owner may need to choose among first cost, downtime, energy, redundancy, comfort, maintainability, phasing, or future flexibility. The engineer's role is to define the consequences of the reasonable options clearly enough for an informed decision, then document the accepted direction.

Several paths may be required at once. A relocated differential-pressure sensor, for example, may require a field correction to relocate the sensor, a controls revision to restore or improve reset logic, a design-record update, and a functional retest. Increasing the pump setpoint alone might improve remote flow temporarily, but it would not close the underlying design-to-field discrepancy.

Before closing a correction, ask four questions:

- Did the action address the identified mechanism rather than only the symptom?
- Did the action create a new effect elsewhere in the system?
- Were the accepted documents, sequence, setpoints, or as-built records updated where necessary?
- Was the corrected condition verified under the operating mode that originally exposed the problem?

This correction-path discipline is what turns troubleshooting into controlled engineering change rather than trial-and-error adjustment.

6.2 HOW TO DISTINGUISH DESIGN, INSTALLATION, CONTROL & OPERATION FAILURES

HVAC troubleshooting improves when the investigator classifies the mechanism rather than the person responsible.

DESIGN CONDITION

The installed system matches the design, but the design cannot achieve intended performance. Examples: insufficient pressure basis; poor zoning; incomplete sequence; inappropriate sensor concept; and inadequate equipment selection.

INSTALLATION CONDITION

Design is reasonable, but field installation does not conform. Examples: reversed valve; obstructed duct; wrong damper; sensor installed in wrong location; missing insulation; and improper trap.

CONTROL IMPLEMENTATION CONDITION

Physical system is adequate, but programming does not match the accepted sequence. Examples: wrong reset; missing interlock; incorrect point mapping; improper alarm delay; and failure response omitted.

OPERATION CONDITION

System was accepted correctly but later operation changes it. Examples: persistent override; altered schedule; changed setpoint; disabled alarm; and maintenance issue.

COMMISSIONING/VERIFICATION GAP

The defect existed but was not identified before turnover. These categories can overlap. The purpose is diagnosis, not blame.

6.3 USE EVIDENCE HIERARCHY DURING TROUBLESHOOTING

When documents conflict, identify which source represents the accepted condition.

Possible sources include: OPR; BOD; contract documents; approved submittals; RFIs; field changes; and final sequences. Additional considerations include TAB report; commissioning report; as-built drawings; BAS programming; trend data; and field measurement.

The latest field programming may be the actual operation but not the accepted design. The original design sequence may be contractually authoritative but obsolete after approved changes. The engineer should reconstruct the chain rather than assume one document tells the full story.

6.4 A GOOD CORRECTIVE ACTION PRESERVES THE SYSTEM

HVAC corrective work can shift problems. Increasing fan pressure may improve one zone but increase noise elsewhere. Lowering supply-air temperature may solve comfort but increase reheat. Opening outside air may address odor but create humidity. Increasing pump pressure may improve remote flow but destabilize valves. The correction should therefore be tested for secondary consequences.

Ask:

- What other zones/systems change?
- What energy effect occurs?
- What control limit changes?
- What maintenance effect occurs?
- Does the correction violate another requirement?
- Does documentation need update?
- Does commissioning need repeat?

6.5 DOCUMENT THE FINAL ACCEPTED CONDITION

After troubleshooting, the accepted correction should be reflected in controlled records. If the sequence changes, update the sequence. If a sensor moves, update drawings/points documentation. If setpoint limits change, update the systems manual. If equipment changes, update schedules and O&M information. A building should not depend on oral knowledge that disappears with personnel turnover.

6.6 FINAL INTEGRATED REVIEW FRAMEWORK

The following framework summarizes the course.

DESIGN INTENT

- What is the system supposed to do?
- Under what conditions?
- What owner requirement does it satisfy?

DESIGN BASIS

- What loads, assumptions, standards, capacities, and operating concepts support the design?

CONSTRUCTABILITY

- Can the design be installed, accessed, maintained, replaced, drained, insulated, supported, and phased?

DISTRIBUTION

- Can air/water reach the required locations over the full operating range?
- Can it be measured and balanced?

CONTROLS

- Can the BAS execute the intended operation?
- Are modes, transitions, resets, safeties, alarms, and failures defined?

COMMISSIONING

- Can each important requirement be functionally verified?
- What evidence proves acceptance?

OPERATIONS

- Can the owner understand and maintain the accepted system?

When these layers align, the system has a much greater chance of delivering durable performance.

Course conclusion

Professional HVAC engineering is not complete when the load calculation is finished or the equipment schedule is issued. The engineer's design must survive: coordination; procurement; substitution; installation; controls programming; testing, adjusting, and balancing (TAB); commissioning; turnover; and operation. Design review, constructability, controls, and commissioning are therefore not separate administrative tasks. They are four views of the same engineering system. A design review asks whether the concept is coherent. Constructability asks whether physical reality preserves that concept.

Controls ask whether the system can behave as intended. Commissioning asks whether the installed system can prove that behavior. The most effective engineers move among all four perspectives. They do not assume a capacity schedule guarantees performance. They do not assume a clash-free model guarantees maintainability. They do not assume a BAS point guarantees a physical result. They do not assume startup guarantees sequence performance. They use measured evidence, explicit design intent, disciplined documentation, and controlled testing to close the gap between drawing and operation.

Principal references and source links

- NIST Technical Note 2024, Commissioning ASHRAE High-Performance Sequences of Operation for Multiple-Zone VAV Air Handling Units, February 2019. Tables 4–5 and implementation findings. Open source
- ANSI/ASHRAE Standard 55-2023, Thermal Environmental Conditions for Human Occupancy. Open source
- ANSI/ASHRAE Standard 62.1-2025, Ventilation and Acceptable Indoor Air Quality. Open source
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- ASHRAE Guideline 36-2024, High-Performance Sequences of Operation for HVAC Systems. Use the applicable published addenda and errata. Open source
- ANSI/ASHRAE/IES Standard 202-2024 and ASHRAE Guideline 0-2019, commissioning process publications. Open source
- ASHRAE Guideline 1.1-2025, Application of the Commissioning Process to New HVAC&R Systems. Open source
- Florida Building Commission: governing code and 9th Edition (2026) transition resources. Open source
- NCEES PE Mechanical: HVAC and Refrigeration examination specifications, effective October 2025; scope reference. Open source

Public publisher and agency source information checked November 15, 2026. Technical examples support engineering judgment; use the governing project requirements, adopted code edition and applicable standard for implementation.

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