EnergyDesignResources.Com

Cx Assistant^{TM}

Design Review Tool Module
Master Reference Guide

Developed by
Portland Energy Conservation, Inc.

Under contract to
Pacific Gas and Electric Company

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IMPORTANT NOTICE: This sample document is provided for instructional purposes only. The document is not rendering advice concerning any commission project or practices. This document is neither approved nor intended to serve as a standard form. The user of these documents should confer with qualified advisors with respect to commissioning and other documentation.

About Cx Assistant

Energy Design Resources' Commissioning Assistant is a web-based tool designed to provide project-specific building commissioning information to design teams. The tool, found at http://www.energydesignresources.com/resource/176, currently enables the users to accomplish the following nine functions:

1. Evaluate probable commissioning cost.
2. Identify the appropriate commissioning scope for each project, and develop sample scope documents.
3. Develop a sample design intent document with specific inputs from their projects.
4. Develop a sample basis of design document with specific inputs from their projects.
5. Access sample commissioning specifications related to specific inputs for his/her construction project.
6. View sample sequence of operations for ten specific HVAC system types based upon the requirements in California Title 24-2005.
7. Develop a sample Commissioning Plan with specific inputs from their projects.
8. Develop a sample Training Plan with specific inputs from their projects
9. Develop a sample Systems Manual with specific inputs from their projects

Cx Assistant Design Review Checklist:

This module generates customized Design Review Checklists that can be used to facilitate design reviews or to communicate to designers the issues that their designs should address. The Checklists can be used during the design development, construction document, or submittal phase of the design.

Checklists covering eighteen design review areas include key topics such as maintainability, constructability, and common energy efficiency issues. When using the online version, the checklist is determined by the user's chosen systems and phase of review, with the ability to filter for energy efficiency issues. References are provided to guide users unfamiliar with the technical topics.

The Design Review Checklist module allows the user to access a complete reference that includes all checks or to generate a checklist containing only issues relevant to their project. To allow further customization, the Checklists are delivered in a Microsoft Word format. This document is intended as a reference document and contains all of the eighteen review areas.

Each review area contains the following codes to show the phase in which each check should be completed. The check should normally be completed at the phases listed to the right of each check, according to the following key.

DD: Design development phase

CD: Construction documents phase

S: Submittal review (contractor construction submittal of equipment data and shop drawings)

XX: Perform a review of this issue during this stage. If not shown sufficiently, ask the question or request information from the design team as part of this review. Do not wait until the next phase. An XX in both DD and CD phases indicates that the issue needs review in both phases.

X: Perform a review of this issue if there is sufficient detail, otherwise wait until the next design submission.

About EDR
Energy Design Resources offers a valuable palette of energy design tools and resources that help make it easier to design and build energy-efficient commercial and industrial buildings in California. The goal of this effort is to educate architects, engineers, lighting designers, and developers about techniques and technologies that contribute to energy efficient nonresidential new construction. Additionally, design tools that reduce the time you spend evaluating the energy use impact of your design decisions are provided here at no cost. Plus, we've designed them to be quick and easy to learn so you can begin designing more efficiently today.

Did you know: Even though California already leads the nation in energy-efficient building construction, the state tightened its energy standards for new construction in 2005?

We want to help make it as easy as possible for you to transition to these new regulations. Perhaps more importantly, we also want to help you exceed these standards to create more efficient buildings that will be less expensive to own and operate. This approach should make owners, tenants, and clients happy.

The development of Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, Southern California Edison, and Southern California Gas under the auspices of the California Public Utilities Commission.

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1. Sequence of Operation and Control Drawing Issues

Control system design is an area that requires the ability to remain focused on the big picture, while paying significant attention to detail and interdisciplinary coordination. As control systems become increasingly complex and specialized, it is difficult for design engineers to remain current in their knowledge of their capability and limitations. Hence, there may be a temptation to rely on the controls contractor to make many control design decisions. This approach neglects the fact that many modern designs are based on the complex interaction of multiple systems, each of which may have a distinct control system (e.g., controls provided by the chiller and boiler manufacturers which must interact with the BAS). It is the designer who has the complete knowledge of the big picture. Consequently, the construction documents should include sufficient detail to provide a finished product that implements the basis of design without requiring the contractors, commissioning authority, or operating personnel to resort to guesswork, make assumptions or submit RFIs. Such detail should include control schematics which graphically depict the systems, sensors and control points associated with the system components and detailed sequences of operation that describe how the equipment operates through all modes.

Below are thirteen areas that should be checked in design reviews:

1. Control schematics are provided in the drawings for each piece of equipment and all input and output devices
2. Control sequences exist for all applicable equipment and modes of operation
3. Sequences are clear and coordinated
4. All applicable basic sequences are included
5. All needed sequences are included for air handling equipment
6. All needed sequences are included for the VAV air terminal units
7. All needed sequences are included for the chilled water system
8. All needed sequences are included for the heating water system
9. Response to power and controller failures and reset requirements are provided
10. There are no conflicts between control sequences and equipment details, point lists, sequences on drawings, the designers' intent and the basis of design
11. Contractor submittal requirements for the sequences of operation are rigorous, clear and appropriate for the application
12. Contractor submittal requirements for the control drawings are rigorous, clear and appropriate for the application
13. Contractor submittal includes sequences as specified

1. Control schematics are provided in the drawings for each piece of equipment and all input and output devices

Checks:

		DD	CD	S
A.	Control schematic drawings are provided for each piece of equipment controlled or monitored by the building automation system (BAS).	X	XX	XX
B.	Schematics for BAS controlled equipment include all input & output devices, including sensors, meters, controllers, fans, pumps, dampers, valves, VFD, coils, heat exchangers, etc.	X	XX	XX
C.	Control schematic drawings are provided for each piece of equipment controlled by packaged controls.	X	XX	XX
D.	Schematics for packaged equipment include all devices, meters, controllers, fans, pumps, dampers, valves, VFD, coils, heat exchangers, sensors (packaged and BAS), set points and start/stop points from the BAS or from breakers, switches, timers or thermostats and interlocks to other equipment, etc.	X	XX	XX

2. Control sequences are provided for all applicable equipment and modes of operation

Checks:

		DD	CD	S
A.	Sequences exist for each piece of equipment listed in the equipment schedule that are monitored or controlled by the BAS.	X	XX	XX
B.	The major sequences of operation and the primary features to be set up and included in this project are listed for equipment operated by all standalone packaged controls. Adjustable parameters such as set points, lockouts and interlocks are provided. For complete equipment, this may be in the technical section rather than the control section of the specifications. For smaller components not monitored by the BAS, but part of a larger system (such as cooling tower sump heater or makeup water valve), the sequences should be listed in the technical section and with the main equipment BAS sequences in the controls section, for reference and continuity.	X	XX	XX

		DD	CD	S
C.	Control sequences are specified for all smaller equipment such as: unit heaters, finned tube radiation, domestic hot water system, sump pumps, lighting occupancy sensors, building exterior lighting, etc.	X	XX	XX

3. Sequences are clear and coordinated

Checks:

		DD	CD	S
A.	Sequences are written in small numbered statements.	X	XX	XX
B.	Sequences are grouped by headings (Startup, Warm-up, Unoccupied Mode, Alarms, Capacity Control, etc.).	X	XX	XX
C.	Sequences for a given piece of equipment are all “stand alone”, meaning specific sequences do not reference back to common sequences located somewhere else.	X	XX	XX
D.	Control strategies and sequences of operation are not too complex for the level of understanding or the resource availability of the building operators.	X	XX	XX

4. All applicable basic sequences are included

Checks:

		DD	CD	S
A.	Sequences clearly describe the specific control logic required for implementation, including response of all output devices to all inputs. When the BAS interacts with a control system provided with the equipment, the sequence describes what functions are to be performed by which control system, what specific information is to be exchanged, and how this interaction is to occur.	X	XX	XX
B.	An overview narrative of the system describing its purpose, components, function and areas served is included.	X	XX	XX
C.	A points table is included for each piece of equipment including at least the point type (AI, AO, DI, DO, virtual), units and whether it’s to be shown on user graphic.	X	XX	XX
D.	Start-up sequences, including parameters, lockouts and interlocks with other equipment are described.	X	XX	XX
E.	Normal operating mode sequences, including capacity modulation and staging are described.	X	XX	XX

		DD	CD	S
F.	Cycling off sequences and parameters are given.	X	XX	XX
G.	Dead bands and delays or other means to prevent short cycling of equipment are included.	X	XX	XX
H.	Unoccupied mode sequences, including occupant override sequences are included.	X	XX	XX
I.	Shutdown sequences and emergency modes are included.	X	XX	XX
J.	Sequences describe the effects of loss of power at the general building level and at the local disconnect level, including how the local controller and each piece of equipment will respond, and methods used for resetting the equipment to get it running again.	X	XX	XX
K.	Effects of loss of power or communication with each local controller and the general network and how the local controller and each piece of equipment will respond and methods used for reset are given.	X	XX	XX
L.	Sequences for all alarms and safeties are described. The failure alarm that is generated is specified for each component. The local alarms passed to the building automation system (BAS) are specified. The response of the system to each alarm is specified (register in the BAS alarm history, pop-up on the workstation screen, page out, etc.).	X	XX	XX
M.	Response to any interlocking fire or smoke alarms and the reset method required is given.	X	XX	XX
N.	Seasonal operational differences and recommendations are shown.	X	XX	XX
O.	Initial and recommended values for all adjustable settings, set points and parameters that are typically set or adjusted by operating staff are listed. Ideally, some guidance is given on how to determine the optimal set point.	X	XX	XX
P.	Other control settings, fixed values, and control methods that will need to be known to fully test and troubleshoot the system are provided.	X	XX	XX
Q.	All points that may need to be adjusted during set up, operation or troubleshooting are listed as “adjustable.”	X	XX	XX
R.	Monitoring points needed for testing, troubleshooting or optimizing control are listed.	X	XX	XX
S.	Equal run-time sequences, if included, are given.	X	XX	XX
T.	Time of day schedules, as provided by the owner, are listed.	X	XX	XX

5. All needed sequences are included for air handling equipment

Checks:

		DD	CD	S
A.	All applicable basic sequences are included (see list in the Basic Sequences section).	X	XX	XX
B.	Damper and fan interlocks are listed.	X	XX	XX
C.	Warm-up or cool-down mode is described.	X	XX	XX
D.	Night high and low limits are given and sequences described.	X	XX	XX
E.	Night set back mode operation is given.	X	XX	XX
F.	Discharge and/or supply air temperature control, including resets, heating and cooling coil valve control and dead bands between heating and cooling, are described.	X	XX	XX
G.	Mixed air temperature control sequences are provided, ideally with independent actuators provided for return, outside, and relief air dampers.	X	XX	XX
H.	Economizer control sequences are given.	X	XX	XX
I.	Minimum outside air control is thoroughly described.	X	XX	XX
J.	Building static pressure control, including fan speed low limits are specified.	X	XX	XX
K.	Return or relief fan control and relief damper control are described.	X	XX	XX
L.	Freeze protection control sequences are provided.	X	XX	XX
M.	Humidity control sequences are provided.	X	XX	XX
N.	Compressor and condenser fan staging for DX units is described.	X	XX	XX
O.	Duct static pressure control, including resets, are described with set points and parameters.	X	XX	XX
P.	High duct static pressure on supply fan (for large fans, low pressure return duct static) alarm and control is described.	X	XX	XX
Q.	Heat pipe or heat exchanger control sequences are given.	X	XX	XX
R.	Smart alerts indicating when critical parameters go out of spec (for energy savings or process control safety) are provided.	X	XX	XX
S.	Fan failure modes are described.	X	XX	XX
T.	Dirty filter alarms are listed, with set points.	X	XX	XX
U.	Special isolation damper controls are described.	X	XX	XX

		DD	CD	S
V.	Night flush sequences are given, when included.	X	XX	XX
W.	Monitoring points are specified such as: temperature between the heating and cooling coils (for valve leak-by detection), mixed air temperature, return air temperature, and return air relative humidity.	X	XX	XX

6. All needed sequences are included for the VAV air terminal units

Checks:

		DD	CD	S
A.	All applicable basic sequences are included (see list in the Basic Sequences section).	X	XX	XX
B.	Control schematic is included showing set points, dead bands and throttling ranges.	X	XX	XX
C.	Interlocks to supply fans or time of day schedules are provided.	X	XX	XX
D.	Interlocks to occupancy sensors and lighting controls are described.	X	XX	XX
E.	Sequences are clear about how the heating and cooling set points work (separate set points or a common single set point with biases or offsets, etc.).	X	XX	XX
F.	Initial values are given for all set points.	X	XX	XX
G.	User adjustable set point limits are given.	X	XX	XX
H.	Damper control and flow control sequences are described.	X	XX	XX
I.	Reheat functions, lockouts and minimum flow for electric reheat are described.	X	XX	XX
J.	Parallel or series fan control sequences are given.	X	XX	XX
K.	Sequences for demand controlled ventilation (CO_2) are provided.	X	XX	XX
L.	Night set back operation is described.	X	XX	XX
M.	Night low and high limit operation is described.	X	XX	XX
N.	Unoccupied mode and occupancy override functions are described.	X	XX	XX
O.	Monitoring points, such as VAV terminal unit supply air temperature, are listed.	X	XX	XX

7. All needed sequences are included for the chilled water system

Checks:

		DD	CD	S
A.	All applicable basic sequences are included (see list in the Basic Sequences section).	X	XX	XX
B.	The parameters that enable the chillers and the chilled water pumps to start are given.	X	XX	XX
C.	Startup sequences for pumps, chillers, towers, etc, are described.	X	XX	XX
D.	Chilled water temperature control sequences, including resets, are given. Whether the BAS or the chiller controller is exercising the sequence is identified.	X	XX	XX
E.	Cooling tower leaving water temperature control, reset, and fan capacity staging (towers enabled, isolation valves, fan speed, bypass valve, etc.) are described.	X	XX	XX
F.	Variable chilled water flow control sequences are described.	X	XX	XX
G.	Variable condenser water flow control parameters are described.	X	XX	XX
H.	Chiller staging control is described in detail. Both staging up and staging down sequences and parameters are listed. Delays, dead bands and other specific measures designed to prevent short cycling are given.	X	XX	XX
I.	Methods or features used to accommodate operation at very low loads are described.	X	XX	XX
J.	Sequences for cooling tower sump heater controls are given.	X	XX	XX
K.	Cooling tower makeup water controls are described.	X	XX	XX
L.	Cooling tower chemical treatment and filtration controls are described.	X	XX	XX
M.	Winter operation of towers and freeze protection are described.	X	XX	XX
N.	Refrigerant leak safeties, detection, alarm and interlocks to and from fans and safety equipment operation are described.	X	XX	XX
O.	Chiller room temperature and ventilation control and interlocks are described.	X	XX	XX
P.	Minimum chiller on or off times and maximum recycle times are listed and described.	X	XX	XX

		DD	CD	S
Q.	Primary chilled water pump control, including variable speed control, (if applicable) is described.	X	XX	XX
R.	Secondary loop pump and pressure control, including set point, reset, sensor location, minimum pump speed, and pump ramp times are described.	X	XX	XX
S.	Chiller and pump equal run time controls are described.	X	XX	XX
T.	Standby sequences of chillers, pumps, tower fans and variable speed drives to accommodate failed equipment are described.	X	XX	XX
U.	Chiller selection and capacity controls for optimizing efficiency are described.	X	XX	XX
V.	Demand limiting functions are described.	X	XX	XX
W.	Sequences for all alarms and safeties. The chiller panel alarms that are passed to the BAS are shown. It indicates whether the alarm simply registers in the BAS alarm history, or is a pop-up on the workstation screen, a page out, etc.	X	XX	XX
X.	Monitoring points are listed such as: kW or kW/ton, temperatures on all four hydronic legs of the primary/secondary bypass pipe, chilled water supply temperature on all chillers, condenser head pressure reference (internal chiller point), cooling tower vibration, high level and low level alarms, make up flow and blow down flow accumulation, basin heater and heat trace proof of operation.	X	XX	XX

8. All needed sequences are included for the heating water system

Checks:

		DD	CD	S
A.	All applicable basic sequences are included (see list in the Basic Sequences section).	X	XX	XX
B.	The parameters that enable the boilers and the heating water pumps to start are given.	X	XX	XX
C.	Start-up sequences including parameters and lockouts and interlocks with combustion fans are described.	X	XX	XX
D.	Normal operating mode sequences, including capacity modulation and boiler staging, cycling off sequences and parameters, and dead bands and delays or other means listed that will prevent short cycling of boilers on and off are described.	X	XX	XX

		DD	CD	S
E.	Unoccupied mode sequences are described.	X	XX	XX
F.	Boiler tank temperature control is described.	X	XX	XX
G.	Primary loop temperature control is described.	X	XX	XX
H.	Secondary loop water temperature control (setbacks, setups, resets, etc.) is described.	X	XX	XX
I.	Primary loop circulation pump control is described.	X	XX	XX
J.	Secondary loop pump and pressure control, such as set point, reset, sensor location, minimum pump speed, and pump ramp times are described:	X	XX	XX
K.	Monitoring points, such as burner stage or boiler temperature, are listed.	X	XX	XX
L.	Effects of power or equipment failure with all standby equipment functions (boilers, pumps, isolation valves) are described.	X	XX	XX
M.	Sequences for all alarms and safeties are provided. The boiler panel alarms that are passed to the BAS are shown. It indicates whether the alarm simply registers in the BAS alarm history, or as a pop-up on the workstation screen, as a page out, etc.	X	XX	XX
N.	Actions for any emergency stop switches are given.	X	XX	XX
O.	Standby sequences of boilers, pumps and variable speed drives to accommodate failed equipment are described.	X	XX	XX
P.	Boiler room ventilation, combustion air and temperature control and interlocks are described.	X	XX	XX
Q.	Equal run-time sequences, if included, are described.	X	XX	XX

9. Response to power and controller failures and reset requirements are provided

Checks:

		DD	CD	S
A.	Equipment and system response are provided for both a general power outage and for a local equipment failure - including component shut down - in non-damaging sequences (e.g., dampers stay open until fans are at least spinning down). Special care has been taken in describing these sequences so the contractor knows how the variable frequency drives must communicate with the BAS. Note: there may be special cases or code requirements for some emergency situations.	X	XX	XX

B.	Equipment and system response are provided for both a local controller failure and for a general network failure - including component shut down - in non-damaging sequences (e.g., dampers stay open until fans are at least spinning down). Special care has been taken in describing these sequences so the contractor knows how the variable frequency drives must communicate with the BAS.	X	XX	XX
C.	After a power outage and controller or network communication are restored, sequences are provided for what will start automatically, what will require a reset at the BAS work station and what will require a manual reset at the unit. The sequences describe how components are started in non-damaging sequences (e.g., dampers open prior to fans energizing).	X	XX	XX
D.	During startup, systems are staged on so that electrical load is limited to avoid tripping breakers or creating large demand spikes.	X	XX	XX

10. There are no conflicts between control sequences and equipment details, point lists, sequences on drawings, the designers' intent and the basis of design

Checks:

		DD	**CD**	**S**
A.	The respective functions of any packaged controls and the building automation system are clearly delineated, listing what are monitoring-only points and what are control points and adjustable.	X	XX	XX
B.	Drawings and specifications indicate sufficient control points for specified control sequences.	X	XX	XX
C.	Appropriate equipment features listed in the technical section of the specifications are covered in the specification sections containing the sequences of operation.	X	XX	XX

11. Contractor submittal requirements for the sequences of operation are rigorous, clear and appropriate for the application

Checks:

		DD	CD	S
A.	Specific items are added to the requirements for the contractor control sequences submittals to address any identified deficiencies in the sequences of operation in the specifications that are not likely to be resolved in the specification reviews. Consider the list of basic sequences elements listed below.	X	XX	XX
B.	The submittal requirements state that the sequences submittal will not just be a copy of the sequences in the specifications, but will include all needed clarifications, such as dead bands, delays, ramp times, loop type (PID, PI, etc.), changes in parameter comparisons for resets, added sequences required to properly operate the equipment, etc.	X	XX	XX

12. Contractor submittal requirements for the control drawings are rigorous, clear and appropriate for the application

Checks:

		DD	CD	S
A.	Requirements are included for the submittal to provide a network architecture drawing showing all controllers, workstations, printers, and other devices in a riser format, including protocols and speeds for all trunks.	X	XX	XX
B.	Requirements are included for the submittal to provide a table of contents and a key to all abbreviations (including all abbreviations in schematics and points list column headings and cell contents).	X	XX	XX
C.	Requirements are included describing what items should be provided in the submittal on the graphic schematic depictions for all systems. Items required to be provided on the graphics include: all components, valves, dampers, actuators, coils, filters, fans, pumps, speed controllers, piping, ducting, each monitored or control point and sensor, all interlocks to other equipment, fan cfm, pump gpm and horsepower by each element. There is a requirement to list the location of remote points that are off the schematic, like static pressure sensors, outside air sensors, etc.	X	XX	XX

		DD	CD	S
D.	Requirements are included for the submittal to provide system and component layout of any equipment that the control system monitors, enables or controls, even if the equipment is primarily controlled by packaged or integral controls.	X	XX	XX
E.	Requirements are included for the submittal to provide a full points list with at least the following required for each point: point abbreviation / name, point type (AI, AO, DI, DO, virtual), system with which the point is associated, point description, display unit, panel address, ID and location, reference drawing number from the blueprints and field device type (temperature sensor, starter, contactor, static tip, etc.).	X	XX	XX
F.	Requirements are included for the submittal to provide a room schedule, with at least the following information for each room: floor, room number, room name, air hander ID, reference drawing number, air terminal tag, heating and cooling valve tag ID, cold and hot pipe size, K factor, minimum and maximum cfm for both heating and cooling, actuator signal range and type.	X	XX	XX
G.	Requirements are included for the submittal to provide a valve schedule, including at least: valve tag, system tag (air hander or terminal), service (heating or cooling), quantity, action (2-way, 3-way), fail position, body style, size, close-off pressure, gpm or lb/hr, design Cv, actual Cv, design differential pressure (DP), actual DP, actuator type, control signal range and comments.	X	XX	XX
H.	Requirements are included for the submittal to provide sketches of all graphics screens for review and approval.	X	XX	XX
I.	Requirements are included for the submittal to provide a graphic penetration tree showing all graphics screens.	X	XX	XX

13. Contractor submittal includes sequences as specified

Checks:

		DD	CD	S
A.	Controls contractor has incorporated all specific equipment/system requirements as stated in the specifications.			XX
B.	All interactions and interlocks with other systems are listed.			XX

		DD	CD	S
C.	Needed clarifications to the specified sequences have been made in the submittal version, such as dead bands, delays, ramp times, loop type (PID, PI, etc.), changes in parameter comparisons for resets, etc. Such changes are flagged if they may go beyond the design intent and require engineer approval, or are inefficient or ineffective.			XX

Resources

ASHRAE. (2003) "Supervisory Control Strategies and Optimization," *ASHRAE HVAC Applications*.

California Energy Commission. (2004) "Reference Specifications for Energy and Resource Efficiency." California Energy Commissioning website, http://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

Energy Design Resources. (2004) "Cx Assistant, Sequences of Operation." California Commissioning Collaborative website, http://www.cacx.org/resources/samples.html. Accessed Dec 2006.

2. Sensor Issues

Sensors are the frontline of a control system, as they identify the conditions of spaces and the conditions within equipment that is used to condition the spaces. When sensors are specified inappropriately, or installed or set up improperly, the control system is not likely to be able to provide the comfort and energy efficiency expected.

Below are four areas where design reviews can provide significant value.

1. Control points shown in the drawings and specifications are sufficient for the specified control sequences and needed monitoring
2. Sensor locations are specified or shown in the drawings and are correct
3. Sensor type and accuracy is correct for the application
4. Requirements for field calibrating sensors are provided in the specifications

1. Control points shown in the drawings and specifications are sufficient for the specified control sequences and needed monitoring

Checks:

		DD	CD	S
A.	Only sensors that are necessary for the control sequences and useful monitoring points for testing, fine-tuning, troubleshooting, performance tracking, and operations are shown, as required.	X	XX	
B.	Refer to Review Area 1 Sequences of Operation and Control Drawing Issues and Review Area 3 Control Software and Hardware for further information on sufficient control and monitoring points.	XX	XX	

2. Sensor locations are specified or shown in the drawings and are correct

Checks:

		DD	CD	S
A.	For each hydronic flow sensor, the locations are shown on the drawings with detail notes indicating the length of straight pipe required up and downstream of the sensor. Distances vary with single vs. dual turbine models. Typically the nearest pipe fitting must be at least 10 pipe diameters upstream and 5 diameters downstream of the sensor	X	XX	

		DD	CD	S
B.	The outside air temperature sensor is specified or shown to be in a commercially designed solar shield located on a north wall or some other location out of direct sunlight. The sensor should not be close to a roof surface or masonry wall that will reflect direct sunlight or emit absorbed radiation to the sensor, and it should not be close to sources of exhaust air. Sensors mounted in the outdoor air intake duct of air handlers are only acceptable on units that operate 24 hours per day.	X	XX	XX
C.	Averaging sensors are used for mixed air and temperatures off the discharge of heating or cooling coils in units larger than about 10 tons, as well as for large ducts or in configurations where stratification may occur.	X	XX	XX
D.	The mixed air temperature sensor is an averaging type with at least 1 lineal foot of sensor per every 2 to 4 square feet of filter or coil face area, depending on the likelihood of stratification and the importance of the reading. Instructions are shown in the specifications to install the sensor in a uniform serpentine pattern and to customize the pattern to catch any non-uniform air flow in the mixed air plenum. Wiring multiple point or averaging sensors in series can also provide an acceptable average.	X	XX	XX
E.	Freezestats are specified to be mounted in a serpentine pattern and utilize at least 1 foot of element per 4 square foot of coil area with radius clips at each bend.	X	XX	XX
F.	Wall mounted thermostats in walls that extend below pressurized raised access floors are installed in completely air sealed and insulated junction boxes. The conduit at both ends is sealed around the wiring.	X	XX	XX
G.	Each wall mounted thermostat is located away from potential sources that would adversely affect the reading (close to copiers, direct sunlight, below or above a supply air diffuser or convector, etc.). Compare thermostat location drawings with furniture layout drawings, if available. Each thermostat is located in a representative location for the zone. Any thermostats mounted on exterior walls are installed in sealed and insulated junction boxes.	X	XX	XX
H.	Pipe-mounted immersion well sensors are specified to be installed with thermal grease. Applications requiring a fast response are direct immersion type sensors mounted through a full port ball valve.	X	XX	XX

		DD	CD	S
I.	For CO_2 sensor guidelines, see Review Area 14 Outdoor Air Control Issues.	X	XX	XX
J.	The static pressure sensor used for duct static pressure control is shown on the drawings and is located about ¾ the way down from the fan to the last air terminal unit on the hydraulically longest branch. If the duct static pressure is being reset, this distance is not as critical.	X	XX	XX
K.	The duct static pressure sensor is located away from fittings that will cause erratic flow and pressures.	X	XX	XX
L.	Building and space static/differential pressure sensor guidelines are found in Review Area 17 Building and Space Pressurization Issues.			
M.	Hydronic loop pressure sensors used for controlling pump speed are shown located across the last load (coil and control valve) of the hydraulically longest leg.	X	XX	XX
N.	Smoke detectors are located far enough away from humidity generators so they will not set off smoke alarms. The distance is dependent on the type of smoke detector and capacity of the humidifier, but the designer should be questioned if they are within 15 feet of each other.	X	XX	

3. Sensor type and accuracy is correct for the application

Checks:

		DD	CD	S
A.	Acceptance criteria for the tolerances of controlled or monitored values (such as room temperature) are addressed in the Owner's Project Requirements (OPR) and the Basis of Design (BOD), and included in the specifications. Specified sensor accuracies and test acceptance criteria are consistent with these requirements.	X	XX	XX
B.	Refer to Review Area 14 Outdoor Air Control Issues for information on CO_2 sensors.	X	XX	XX
C.	Refer to Review Area 17 Building and Space Pressurization Issues for information on air pressure sensors.	X	XX	XX

		DD	CD	S
D.	BAS entering and leaving chilled and condenser water temperature sensors have an accuracy of +/- 0.35°F or better when used for monitoring or control. If they will be used to verify energy savings in a performance contract, more accurate sensors are used and the entering and leaving chilled water sensors are matched.	X	XX	XX
E.	Internal chiller chilled water supply and return temperature sensors are specified to have an accuracy of +/- 0.35°F or better and be a matched pair (within 0.1°F of each other). This is important even when sensors are not used for chilled water supply temperature control, as they will be used by the chiller to monitor low delta-T conditions. Inaccurate readings result in nuisance alerts.	X	XX	XX
F.	Specifications dictate specific requirements for internal chilled water sensors supplied by the chiller manufacturer. (Standard supplied internal chilled water sensors are often not very accurate.) The sequences of operation allow for deviation between the internal and BAS sensors. For example, a lower internal supply temperature reading may result in premature upstaging in some chiller staging sequences.	X	XX	XX
G.	The accuracy for HVAC heating water and domestic hot water system temperature sensors is typically +/- 1.0F.	X	XX	XX
H.	All pressure and flow sensors are specified to be provided with the design pressure or flow near the middle of the device's reading range (this applies to high pressure cutout, duct static, hydronic loop, space differential, building static, hydronic flow meters, etc.).	X	XX	XX
I.	Adjustable current sensors (CT's) are used rather than differential pressure switches to sense motor operation on pumps (to mitigate nuisance trips). The specifications include a requirement to field adjust the sensors to detect the failure of pump couplings and fan belts or drives.	X	XX	XX
J.	Use adjustable differential pressure switches rather than CT's to detect fan failure.	X	XX	XX
K.	Nickel RTD elements for temperature sensors are specified rather than platinum (nickel are more accurate).	X	XX	XX
L.	Airflow sensors are rated to measure flow accurately down to the expected minimum flow (e.g., a pitot type sensor is inaccurate below 20% of rated airflow).			

4. Requirements for field calibrating sensors are provided in the specifications

Checks:

		DD	CD	S
A.	The specifications state that all temperature sensors are required to be checked in the field for calibration, including sensors that have been factory calibrated, unless the sensors are installed in the factory in the equipment prior to shipment and a certificate of the calibration of the installed system is provided. The minimum accuracy of field calibration instruments is specified. The specified accuracy is appropriate for the specified accuracy of the sensor. For commercial office and similar applications, the handheld temperature calibrating instrument should normally have an overall accuracy (instrument + probe) of +/- 0.8°F or better.	X	XX	
B.	The specifications state that temperature sensors without transmitters shall receive a single point calibration. Sensors with transmitters should receive a two point and a slope and intercept calibration when possible.	X	XX	
C.	For chilled and heating water flow meters, the specifications state something similar and appropriately equivalent to the following: “For factory certified calibrated devices: 1) Document that each step by step field installation procedure was followed, AND 2) a) Use a circuit setter, or b) a quality ultrasonic flow meter, or c) take readings from two of the following: a pump curve, a triple-duty valve curve or chiller or coil bundle curve to get a comparative reading of flow. If these methods offer values within 20% of the factory certified calibrated device field reading, assume the device is calibrated and reading properly. Utilizing additional combinations of (a), (b) and (c) is recommended when possible. For non-factory certified devices, utilize (a), (b) or (c) of Step (2).”	X	XX	

		DD	CD	S
D.	For CO_2 sensors, the specifications state something similar and appropriately equivalent to the following: "For CO_2 sensors that monitor space or return air CO_2 that will see essentially the same background CO_2 levels during unoccupied periods: Check the calibration on a random selection of three CO_2 sensors in the building with a calibration test kit. Then perform a relative sensor calibration early in the morning after the building has been unoccupied for at least 8 hours, comparing all other CO_2 sensor readings with the four calibrated sensors. Sensors that are reading greater than 75 ppm different from the calibrated sensor values shall be calibrated. When inside CO_2 sensors are being compared to an outside CO_2 sensor, then an absolute calibration of any sensor is not necessary, only the difference is important, and only a relative calibration is required."	X	XX	
E.	The specifications state that air handler air flow stations shall be calibrated using a duct traverse in an appropriate location and/or a velgrid on a filter or coil bank.	X	XX	
F.	For duct or plenum air temperature averaging sensors, the specifications state something similar and appropriately equivalent to the following: "Calibrate the outside air sensor. Manually close all coil valves. Close return the air damper and open the outside air damper and visually verify seal. Turn on the air handler and verify that the mixed air reading is within specified accuracy tolerance of the outside air reading."	X	XX	

Resources

California Energy Commission. (2004) "Reference Specifications for Energy and Resource Efficiency." California Energy Commissioning website, hhttp://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

PECI, the U.S. Department of Energy, and the California Energy Commission PIER Program. (2006) "Control Systems Design Guide." Functional Testing and Design Guides website, http://www.peci.org/ftguide/. Accessed Dec 2006.

Klaassen, C. (2001) "Installing BAS Sensors Properly," *HPAC Engineering*. August 2001.

National Building Information Controls Program. (2005) "Duct Mounted RH Transmitters Ratings." NBCIP website, http://www.buildingcontrols.org/forms/documents.aspx?d=2. Accessed Dec 2006.

3. Control Software and Hardware Issues

Controls are the brain and nervous system of the HVAC system and significantly impact the comfort, indoor air quality and energy efficiency of a facility. Even the best design concept could fail miserably if the controls are not specified properly. Of all design review areas, control issues are probably the most pervasive and significant, yet the easiest to adjust or correct if identified early during design.

Below are eight areas where design review can provide significant benefit.

Note that these areas and sub-issue checks identify some of the most important issues to review, but a thorough controls review will go beyond these issues. Not all project budgets will support all features suggested in these checks. Also, refer to the review area for Sequences of Control Issues and the review area for Sensor Issues for other related control review items.

1. Network architecture and interoperability meet the owner’s project requirements and follow good industry practice
2. Control system specifications include quantitative network speed performance criteria
3. Emergency and standby functions are properly specified
4. Clear control authorities are shown between packaged and BAS controls
5. Controls design and graphics facilitate optimal maintenance and operation
6. Control valves are properly selected and specified
7. Control dampers are properly selected and specified
8. Acceptance criteria are specified for control loop stability.

1. Network architecture and interoperability meet the owner’s project requirements and follow good industry practice

Checks:

		DD	CD	S
A.	The specifications describe the control system architecture.	X	XX	XX
B.	The specifications describe the peer-to-peer controllers and secondary or application specific controllers and their capabilities.	X	XX	XX

		DD	**CD**	**S**
C.	The means of interaction between specific network and system controllers and equipment and local controllers (for example BACnet, Lon or Modbus) are clearly specified according to the owner's project requirements. Blanket generalized statements about BACnet, Modbus or Lon capability are not adequate. For example, stating that the control system shall be BACnet compatible does not necessarily mean the equipment controllers will be compatible. Also, even if both are specified to be BACnet compatible, it doesn't mean they will necessarily be integrated. It takes labor to obtain equipment point maps and to then map the points and verify they are correct. Specific statements regarding how much information (by data type) will be passed back and forth should be given for each equipment type. The expense of open protocol interface between controllers may not be warranted for all projects.	XX	XX	XX
D.	Any owner requirements and desires for simplicity and maintainability are reflected in system choices. This may include avoidance of undue complexity from interoperability features that require proprietary gateways, updates and programming.	XX	XX	XX
E.	Requirements for offsite/remote accessibility features, including software, hardware and licenses are listed. Monitoring and control features via the owner's intranet and the internet are described with owner responsibilities given. Clear distinction is made between what is to be set up and made operable by the contractor vs. what the system is "capable" of.	XX	XX	XX
F.	Owner's BAS standards are reflected in the design documents, including point naming conventions.	XX	XX	XX
G.	Control devices (sensors, actuators, switches, etc.) are specified to be of the appropriate quality for the project (industrial, commercial or light commercial). Specific performance or accuracy specifications are provided where necessary.	XX	XX	XX
H.	Each type of system contains a one-line control diagram showing sensor and device location and configuration.	X	XX	XX
I.	All sequences of operation can be executed with the devices shown in the control diagram. For example, if the chillers are going to be staged from chiller load based on building chilled water tonnage, the building water flow will need to be monitored. It should be verified that a flow meter is specified.	X	XX	XX

2. Control system specifications include quantitative network speed performance criteria

Checks:

		DD	CD	S
A.	Specifications include a quantitative or performance specification that ensures there will be a sufficient quantity of peer-to-peer primary controllers to handle the number of lower level application specific controllers. Appropriate performance language similar to the following is included: "All sequences of operation described in the specifications, point trending, alarming and normal and emergency functions shall all be capable of being executed without delayed control or a skipped sample or control sequence. This requirement shall be demonstrated during a simulation of moderately heavy network traffic, during which the building systems shall be operated normally, alarms shall be generated, and simultaneous trend logs shall be taken of X% of the total number of system points at a Y minute sampling rate ." Additional language is provided listing explicit performance criteria (response at workstation to alarms, set point changes, start/stop commands, etc.) to require the contractor to provide a design explanation and proposed test procedures.	X	XX	XX

3. Emergency and standby functions are properly specified

Checks:

		DD	CD	S
A.	Controllers for critical applications have redundancy in their power sources. If backup equipment is the source of redundancy, the backup controllers are not powered from the same source. If complete redundancy is required, separate controllers or panels may need to be used for the primary and backup equipment.	XX	XX	XX
B.	Requirements for battery / UPS backup of all network (primary peer-to-peer) controllers and the critical secondary controllers are provided that will ensure critical processes and required power outage sequences can function during power failure.	X	XX	XX

		DD	CD	S
C.	There is a requirement that VFD control interfaces are hardwired with command speed, proof of feedback and status to the BAS controller directly, if they operate equipment that is critical for process or safety. Without hardwiring, the BAS cannot mitigate the effects of a VFD or primary controller fault (e.g., by commanding isolation dampers closed and turning another fan ON).	X	XX	XX
D.	Specifications require that all equipment shall be able to function on at least default or last held values if the central work station and network fail.	XX	XX	XX
E.	As much as possible, all control sequences, set points, and reference points reside in the local BAS controller or on-board controller for major equipment like air handlers, rooftop units, chillers and boilers, so that they do not rely on the network or central work station computer for functioning.	XX	XX	XX
F.	Requirements are provided for hardwired safeties in larger fans systems for high/low duct static pressure and code-required smoke detection.	X	XX	XX

4. Clear control authorities are shown between packaged and BAS controls

Checks:

		DD	CD	S
A.	For packaged air handlers with unit controls, it is clearly specified which functions and devices are provided by the BAS and which are provided by the local control system. Examples include: compressor staging, economizer changeover, minimum outside air and CO_2 demand controlled ventilation, supply air temperature control, fan ramp, duct static pressure control, high duct static shutdown, smoke detector trip, building static pressure control, return or relief fan, relief damper, etc.	XX	XX	XX
B.	For packaged boiler controls it is clearly specified which functions and devices are provided by the BAS and which are provided by the local control system. Examples include: boiler enable and lockouts, boiler temperature, primary loop temperature, secondary loop temperature, boiler staging, standby boiler and pump initiation, alarm functions, etc.	XX	XX	XX

		DD	CD	S
C.	For chiller on-board controls it is clearly specified which functions and devices are provided by the BAS and which are provided by the local control system. Examples include: chiller enable and lockouts, primary chilled water temperature, secondary loop temperature, chiller staging, standby chiller and pump initiation, condenser water and cooling tower functions, alarm functions, etc.	XX	XX	XX

5. Controls design and graphics facilitate optimal maintenance and operation

Checks:

		DD	CD	S
A.	Point naming conventions are explicitly provided or requirements are provided for the controls contractor to obtain naming conventions through meetings with the owner.	X	XX	XX
B.	Monitoring points that will enhance troubleshooting and operation, but are not necessarily needed for control are specified. Examples include: -Temperature: • between heating and cooling coils, • at the discharge of each air terminal unit, • leaving water from each cooling tower (if separate basins), • chiller condenser leaving water just before bypass / mixing valve, • on all four hydronic legs of primary / secondary bypass pipe, • air handler mixed air, • return water from each air handler cooling or heating coil, and • additional outdoor air sensor near air handler unit intakes if main sensor is many stories away or on different sides of a large building -Outdoor relative humidity -Return air CO_2 level	X	XX	XX

		DD	CD	S
C.	Monitoring points that will allow performance monitoring are specified, per the Owner's Project Requirements. Owners that desire to track energy efficiency and usage and/or are applying for the LEED M&V credit require additional monitoring points beyond that needed for control. These may include: major lighting circuit amperage, lighting schedules by zone and sweep controls status by zone, fan kW or amperage, chiller kW/ton (requiring kW, temps and flow monitoring), boiler efficiency (stack temperatures), total building electric consumption, interval electrical demand, and status for motors greater than one horsepower.	XX	XX	XX
D.	The contractor is required to provide sketches of graphic screens and navigation features in their submittal.	X	XX	XX
E.	Graphics screens that contain windows to allow easily adjusting set points that need to be fine-tuned by operations staff are required for all points with "adjustable" in the sequences of operation.	XX	XX	XX
F.	Graphics screens that allow the operator to view an entire site plan graphic and progressively select portions of the site plan for closer inspection are required. Further penetration allows selecting floor plans and then individual pieces of equipment, including all terminal devices, which will display details about the device and the space served.	X	XX	XX
G.	Graphics screens are required that show values at their physical location for all control and monitored points and critical software or calculated points.	X	XX	XX
H.	Applicable sections of the points list with the AI, DI, DO, and AO designations are required to be printed and mounted inside each secondary or local control panel.	X	XX	XX
I.	Each space thermostat is required to have the tag ID of the associated terminal device inside its cover.	X	XX	XX
J.	Sequences of operation text can be easily accessed from appropriate graphics screens.	X	XX	XX

6. Control valves are properly selected and specified

Checks:

		DD	CD	S
A.	Valve actuators have sufficient force to shut off against peak hydronic design pressure (maximum pressure on the pump curve), plus a factor for safety.	X	XX	XX
B.	Modulating valves are sized with a pressure drop slightly larger (10%) than the design flow pressure drop through the load they serve. This usually means the valve size is smaller than the line size.	X	XX	XX
C.	Cv values for modulating valves submitted in the control submittal are generally between 1 and 1.25 times the design scheduled or calculated Cv. Larger values are oversized and may result in poor control. For small valves (like for air terminal units), there are only a few Cv size options, so the above criteria may not always be appropriate.			XX
D.	Two position valves are no smaller than line size.	X	XX	XX
E.	All control and balancing valves are located on the leaving water side of coils. Pressure change across the restriction can allow air to be extracted from the water and become locked inside the downstream coil, inhibiting heat transfer.	X	XX	XX
F.	Actuator power source, failure mode upon loss of power and upon loss of communication and valve operating speed are specified.	X	XX	XX
G.	Butterfly valves are not used for modulating control, without designer explanation.	X	XX	XX
H.	Critical actuator stroke times are specified.	X	XX	XX

7. Control dampers are properly selected and specified

Checks:

		DD	CD	S
A.	Type of dampers being applied to each location are clear in the specifications. If needed, a damper schedule is provided.	X	XX	XX
B.	Damper actuators are direct mounted (rather than linkage actuated), unless a reason not to is provided.	X	XX	XX

		DD	CD	S
C.	Dampers and ducts are specified to be made with materials that are appropriate for the application. Dampers in standard HVAC applications are aluminum or galvanized steel. In high humidity or salt conditions, stainless steel should be used. In high temperature or greasy conditions, ducts and dampers are of black or stainless steel.	X	XX	XX
D.	Parallel blade damper face velocities range up to 1800 – 2200 fpm. Opposed blade damper face velocities are approximately 1000 - 1200 fpm. Larger velocities can result in excessive noise and pressure drop. Lower velocities can indicate oversized dampers and poor control authority. Velocities less than 500 fpm should be questioned.	X	XX	XX
E.	Specific damper leakage requirements are provided. Low leakage dampers are rated at 20 cfm/sf at the required shutoff pressure and in 3” WC pressure ducts. Low leakage dampers should have end seals.	X	XX	XX
F.	Any dampers more than 12 inches high have multiple blades. Damper blade length does not exceed 36 inches.	X	XX	XX
G.	Actuators have sufficient force to shut off tightly against peak design pressure. Torque requirements are shown.	X	XX	XX
H.	For large dampers that must be tight sealing, a sufficient number of actuators are provided to create a tight seal.	X	XX	XX
I.	Vertical oriented blade dampers have thrust bearings on their bottom bearing point.	X	XX	XX
J.	Actuator power source, failure mode upon loss of power and loss of communication and damper operating speed are specified.	X	XX	XX
K.	Damper end switches are specified on larger fan systems with interlocks to fans to prevent duct and damper damage from over-pressurization. For damper banks with multiple sections, provisions are made to address linkage failure.	X	XX	XX
L.	Critical actuator stroke times are specified.	X	XX	XX

8. Acceptance criteria are specified for control loop stability

Checks:

		DD	CD	S
A.	Setpoints and allowable deadbands for temperature, pressure, humidity, and other important control parameters are specified. This is especially important for critical applications such as laboratories, clean rooms and operation rooms.	X	XX	XX
B.	Criteria for maximum allowable deviation from setpoint during steady state operation, and response times after upsets for parameters to come back into deadband are specified for pressure and temperature.	X	XX	XX

Resources

ASHRAE. (2003) "Supervisory Control Strategies and Optimization," *ASHRAE HVAC Applications*.

ASHRAE. (2000) *Specifying Direct Digital Control Systems*. ASHRAE Guideline 13-2000.

PECI. (2006) *Functional Testing Guide: From the Fundamentals to the Field.* Functional Testing and Design Guides website: www.ftguide.org. Accessed Dec 2006.

National Building Controls Information Program. (2006) DDC Online website, http://www.ddc-online.org/. Accessed Dec 2006.

National Environmental Balancing Bureau. (2005) *Design Phase Commissioning Handbook for HVAC Systems*.

Gillespie Jr., Kenneth L. et al. (2006) "A Specification Guide for Performance Monitoring Systems (Draft)." LBNL website, http://cbs.lbl.gov/performance-monitoring/specifications/. Accessed Dec 2006.

4. Maintainability Issues

Frequently, issues faced by operations staff and occupants take a back seat to higher profile aesthetic and budget issues during project planning. Providing the information and system features needed by facility staff and occupants to maintain and occupy the facility is critical to ensuring optimal performance and energy efficiency. The following are maintainability issues that may be overlooked in the drawings and specifications.

Below are five categories of maintainability issues, each with a number of checks.

1. Access for operations and maintenance is adequate and safe
2. Labeling requirements are adequate and complete
3. Training and O&M documentation are adequate
4. Design and as-built documentation left with operators are adequate
5. Needed maintenance features are included

1. Access for operations and maintenance is adequate and safe

Checks:

		DD	**CD**	**S**
A.	All packaged equipment inside rooms can be removed through the doors and halls to outside. Document the owner’s OK otherwise.	X	XX	XX
B.	All roof-top equipment can be replaced via specified roof hoist or a mobile crane.		XX	
C.	Adequate space to pull coils and chiller and boiler tube bundles shown and noted on drawings.	X	XX	X
D.	Adequate space to change fan sheaves and belts shown and noted on drawings.		XX	XX
E.	All devices and equipment above hard ceilings or behind walls that may ever require service have access panels (valves, coils, control and electrical junction boxes, and balancing, isolation and fire/smoke dampers, etc.).	X	XX	
F.	Valves, coils, actuators and control panels on air terminal boxes in ceilings or under floors are accessible for service (no piping, conduit, bracing, ducts or positioning next to walls or columns).		XX	XX
G.	Air terminal units are not located high above drop ceilings, unless ladder access is provided, without being blocked by lower piping, ducting, conduit or drop ceiling grid.		XX	XX

		DD	CD	S
H.	High atrium light fixtures, window and sky light glazing and damper actuators can be accessed via a hi-lift for servicing, without being blocked by permanent planters, stairs, counters, short or narrow doorways, etc.	X	XX	
I.	Permanent ladders or steps with handrails are provided for roof access on roof elevation changes and on cooling towers.		XX	
J.	Air handlers over 10 tons needing regular access for maintenance have hinged access doors (filter, electrical, economizer and fan sections) rather than screwed doors, and maintenance platforms where they are located more than 8 feet above finished floor.		XX	XX
K.	Smaller direct expansion roof top units have a refrigerant hose access plug and high and low taps allowing access panels to be completely closed while test hoses are connected.		XX	XX
L.	Equipment areas are adequately lit for servicing and contain an electrical outlet.		XX	XX

2. Labeling requirements are adequate and complete

Checks:

		DD	CD	S
A.	The model and features of the equipment being supplied are clearly marked in the submittals.		XX	XX
B.	Requirements are included for adequate pipe and duct labeling (arrows and text) utilizing quality materials.		XX	
C.	Non-standard tools and critical spare parts are listed in the O&Ms and/or provided at closeout.		XX	XX
D.	Requirements are included for marking balancing damper and valve positions after final balance, setting set screws to prevent valves from opening too far, and recording balance valve settings in the balancing report.		XX	
E.	Requirements are included for printing and mounting applicable sections of the points list with AI, DI, DO, AO names in each secondary or local control panel.		XX	
F.	Requirements are included for marking inside each space thermostat cover and the tag ID of the associated terminal device.		XX	
G.	Requirements are included for labeling of the ceiling tile grid to indicate which tiles to remove for maintenance access.		XX	

		DD	CD	S
H.	Labeling conventions are approved by owner as consistent with their existing labeling conventions.		XX	
I.	Label names on equipment schedules on plans match control system submittal drawings.			XX

3. Training and O&M documentation are adequate

Checks:

		DD	CD	S
A.	Complexity of system design is appropriate for Owner's maintenance staff.	XX		
B.	Training requirements explicitly list each piece of equipment with training hours. Ideally, all training requirements are located in one section of the specs to avoid contradictions.	XX	XX	
C.	The requirements for recording training sessions (video and/or audio) are well specified and match the Owner's requirements.	XX	XX	
D.	Requirements are included that only qualified trainers, who know this specific project well, can provide training. There is a requirement that resumes be provided for trainers to substantiate their qualifications.	XX	XX	
E.	Specified training topics include all of the following that are applicable to the project: • primary training from O&M manual and control drawings, • description, processes, and objectives of all modes of operation, including resetting after faults, • equipment interface with building automation system, • functional testing results, • occupant training on specialty features like occupancy sensors, daylight dimming, natural ventilation and under floor air distribution. Outlines are required to be submitted for approval prior to each training session.	XX	XX	
F.	Requirements are included for the balancing contractor to review the balance report with staff to go over report format, abbreviations and areas of concern.	XX	XX	

		DD	CD	S
G.	Requirements are included for the O&M manuals and submittals to be provided in electronic format on CDs with a table of contents.	XX	XX	
H.	Requirements are included for O&M manuals to follow ASHRAE Guideline 4 Preparation of Operating and Maintenance Data.	XX	XX	XX
I.	Requirements are included for the labeling convention used to identify equipment in O&M manuals to be consistent with that used elsewhere in the project documents.	XX	XX	XX

4. Design and as-built documentation left with operators are adequate

Checks:

		DD	CD	S
A.	The Owner’s Project Requirements and the designer’s Basis of Design are clear and complete at each design submission (ideally in pre-design). A requirement is provided to include these documents in the Systems Manual, or in some other way to get it into the building operator’s hands.	XX	XX	
B.	Construction submittals are required to be included in the O&M manuals.	X	XX	XX
C.	Riser diagrams provided in design documents for air and water systems show fluid quantities as well as supply, return and exhaust quantities to each floor from each air handler or pump.	X	XX	
D.	Air and hydronic system one-line flow drawings show the round trip flow of the fluid, in simple form. Airside: fans, ducts, dampers, coils, other devices and sensors of air entering, leaving and circulating in the building are shown. Waterside: pumps, valves, coils, sensors and other major devices in the hydronic loop are shown.	X	XX	
E.	Explicit requirements are provided for thorough and accurate as-built drawings, along with a requirement for them to be verified prior to closeout.		XX	
F.	Explicit requirements are provided for thorough and accurate as-built control drawings and fully updated sequences of operation with a requirement for them to be verified prior to closeout.		XX	

		DD	CD	S
G.	Sufficient documentation is provided on the tie-in to and impact of any renovation work on the existing systems		XX	

5. Needed maintenance features are included

Checks:

		DD	CD	S
A.	All mechanical rooms have an adequate sized drain and a water faucet.	X	XX	
B.	Cooling tower areas have a freeze-proof water faucet for cleaning purposes.	X	XX	
C.	Hydronic piping has sufficient manual isolation valves for repairing equipment on one floor or zone without shutting down other floors or zones, especially in critical facilities (laboratories and hospitals).		XX	
D.	Air handlers and exhaust fans in parallel or serving multiple floors have adequate isolation dampers for floor or fan isolation for maintenance.	X	XX	
E.	Level of redundancy is adequate to achieve Owner’s needs while performing routine maintenance.			
F.	Steam coils on outdoor air intakes are properly selected for non-freeze applications, and are properly trapped with adequate drip legs to prevent freezing and are provided with proper controls.	XX		
G.	P-traps are provided with adequate depth to allow proper drainage from the condensate pans, and have provisions for cleaning.		XX	XX
H.	Air handler filter frames in very humid or wet climates are not made of materials supporting mold growth (cardboard). Water resistant cardboard may not deteriorate, but will still support mold growth.	XX		XX
I.	Designer has considered use of fewer larger pieces of equipment to simplify O&M, while still achieving adequate zone control.	XX		
J.	Air filters are secured in factory built racks that minimize leakage and are sized for conventional filter dimensions.		XX	XX

Resources

Feldman, E.B. (1975) *Building Design for Maintainability*.

Construction Industry Institute. (1999) *Design for Maintainability Guidebook*.

California Energy Commission. (2003) “Small HVAC System Design Guide.” California Energy Commissioning website, http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-12.PDF. Accessed Dec 2006.

5. Constructability Issues

During the early stages of a project, designers will generally have a holistic view of a product. As spaces, systems, and equipment get further defined in the design phase, many of the details will be divided among the trades, and there is a potential for coordination conflicts, redundancies, staging issues and other problematic situations. It is important that the holistic view be retained throughout the design and construction processes, so that these potential conflicts will be avoided and the construction phase of the project can go as well as possible in relation to schedule, costs and re-work.

The following are constructability issues that are often overlooked in the drawings and specifications.

Below are four categories of constructability issues, each with a number of checks.

1. Plans for how to bring equipment into the building, space for equipment placement, and piping and ducting layout are all well defined.
2. Coordination of disciplines is adequate.
3. There is adequate coordination of major pathways for duct and pipe to avoid field rerouting.
4. There are no conflicts between general drawings and details.

1. Plans for how to bring equipment into the building, space for equipment placement, and piping and ducting layout are all well defined

Checks:

		DD	CD	S
A.	All equipment inside rooms can be moved through the doors and halls from outside, or a requirement is provided to ship/deliver equipment in sections, or equipment is planned to be installed prior to walls or ceilings being installed (Note: this can create a dramatic increase in difficulty to service and replace).	X	XX	
B.	All rooftop equipment can be placed via roof hoist or crane.	X	XX	
C.	Orientation of major equipment is clearly specified.	X	XX	
D.	Drain lines have required slope specified and there is sufficient room to make the grades (depending upon fluid to be drained).	X	XX	
E.	Drain lines have sufficient cleanouts for initial cleaning and testing.	X	XX	
F.	Exhaust lines and process lines do not exceed the maximum degrees of bend allowed in the specifications.	X	XX	

		DD	CD	S
G.	A plan is provided for access to equipment in high ceilings, atriums or balconies.	X	XX	
H.	There is adequate drainage for testing backflow preventers and fire lines.	X	XX	

2. Coordination of disciplines is adequate

Checks:

		DD	CD	S
A.	When sufficient staging requirements and plans are not found in the specifications, the specifications require a staging or sequencing plan by the contractor which takes into account all subcontractors and their designated roles and contractual requirements, to facilitate adequate planning and coordination.	X	XX	XX
B.	Criteria and responsibilities for repairing damage to existing work by trades are defined.	X	XX	

3. There is adequate coordination of major pathways for duct and pipe to avoid field rerouting

Checks:

		DD	CD	S
A.	Elevation parameters are shown on respective discipline drawings (i.e. bottom of pipe, bottom of duct, bottom of conduit, bottom of cable tray). Drawing sections are included for congested areas.	X	XX	XX
B.	An established priority of installation is provided. Example: drain lines are planned first, as they have priority over ducting.	X	XX	
C.	Scaled distances are indicated on drawings for sensors that are required to be a set distance from corners, valves, pumps, etc.	X	XX	
D.	Piping is not located over electrical panels, transformers or other electrical equipment.	X	XX	
E.	Sufficient landing space at bottoms of ladders and door areas appear to be included.	X	XX	
F.	Gravity sloped drain lines take priority over pressurized piping that does not require sloped installation (unless there is a specific process requirement or lift stations are provided).	X	XX	

		DD	CD	S
G.	High point vents are called out, along with their slope requirements.	X	XX	

4. There are no conflicts between general drawings and details

Checks:

		DD	CD	S
A.	Correct details are associated with layout or general drawing detail callouts.	X	XX	
B.	Drawing details do not require construction parameters that are not provided on the general drawings (i.e. coil piping detail requires pipe lengths that are not possible on the plan drawings).	X	XX	
C.	Compare a random sample of details with the general drawing area they refer to, for accuracy.	X	XX	
D.	Diffusers have adequate clearance for their support connection detail.	X	XX	

Resources

National Environmental Balancing Bureau. (2005) *Design Phase Commissioning Handbook.*

6. Clarity and Detail of Contract Documents Issues

Contract documents (i.e. specifications and drawings) are the marching orders to the contractor. If the contract documents are clear, concise and complete, the contractors will be able to understand how the systems operate, accurately price and provide a functional product, and accurately schedule the project with a minimum of design clarification request and change orders.

Additionally for an owner, clarity and detail in contract documents allows an “apple to apple” comparison of bids to ensure that they gain the best value.

Below are eight categories of clarity and detail issues, each with a number of checks:

1. Detailing of mechanical spaces is adequate, especially with respect to constructability
2. Construction details of critical components are included
3. Abbreviations used are included in the abbreviation schedule and are understandable
4. General drawings and details are consistent and all pertain to equipment used on the project
5. Coordination between different drawings and trades appear adequate
6. Equipment shown on drawings is included and labeled in the schedules
7. Fire/life safety and emergency power response matrices are included and complete
8. System one-line, flow and riser and other needed schematic diagrams are included and complete

1. Detailing of mechanical spaces is adequate, especially with respect to constructability

Checks:

		DD	CD	S
A.	Space coordination with relation to all trades (mechanical, electrical, plumbing, structural and architectural) has been addressed. Priority of system installation is specified in the design, not left up to the contractor.	XX	XX	
B.	Functional equipment move-in paths have been verified (e.g., doors, hallways, corner clearances) and other means of installations are addressed if necessary (e.g., equipment delivered in sections).	XX	XX	

2. Construction details of critical components are included

Checks:

		DD	CD	S
A.	Pump inlet and discharge device and fitting details are provided that do not restrict flow and include all necessary components and test ports.	X	XX	
B.	Coil connection details are included for all situations, and arrangements are simplified to reduce pump energy and construction cost. Separate coil details are provided for non-typical configurations.	X	XX	
C.	Isometric details are included (especially for piping). Isometrics will detail three dimensional physical arrangements that will aide in pressure loss calculations, space coordination and possible simplification of system.	XX	XX	
D.	Inlet conditions for terminal units (typical installation details) are shown.	X	XX	
E.	Sensor installation details are shown, especially flow meters that require a certain number of pipe diameters prior to and after the sensor.	X	XX	
F.	Cross sectional diagrams of major air handling units including fan inlet and discharge conditions are provided.	X	XX	
G.	Piping connections to existing piping systems are clearly shown, including well delineated point of connection and method of connection (e.g., available valve, hot tap, etc.).	X	XX	

3. Abbreviations used are included in the abbreviation schedule and are understandable

Checks:

		DD	CD	S
A.	The abbreviation and symbol table is specific to this project and not a copy of an abbreviation table from another project.	X	XX	
B.	An industry standard abbreviation table is used only if it is appropriate to the specific project and the Owner is agreeable to this standard.	X	XX	

		DD	CD	S
C.	All abbreviations and symbols for processes labeled on piping drawings are found in the abbreviation table. This is assessed by spot checking several abbreviations found in the drawings and verifying that they are found in the table.	X	XX	
D.	If specification sections contain numerous abbreviations, an abbreviation table is included with specifications.	X	XX	
E.	Abbreviations in specification sections and the drawings use the same terminology.	X	XX	

4. General drawings and details are consistent and all pertain to equipment used on the project

Checks:

		DD	CD	S
A.	Details are specific to the project. There are no unneeded generic or extraneous details.	X	XX	
B.	Unique details are provided for similar pieces of equipment whenever the layout is even slightly different (i.e. pumps, coil piping details, etc.).	X	XX	
C.	Details of equipment that has been eliminated or altered have been respectively removed and/or updated on sequential drawing revisions.	X	XX	
D.	When standard details are used, ensure that the location of equipment creates no interference with other equipment or architectural or structural features (i.e. coil pulls).	X	XX	

5. Coordination of backgrounds, anchor points and details between different drawings and trades appear adequate

Checks:

		DD	CD	S
A.	Backgrounds are consistent for all disciplines. The electrical floor plan section is consistent with the respective mechanical plan or section view. Additional section details are provided wherever added detail is required.	X	XX	
B.	Location “key” or map is included on every plan drawing showing detailed area on site or building plan.	X	XX	

		DD	CD	S
C.	Detail callouts on plan or section views are correctly labeled and refer to correct detail drawing sheets.	X	XX	
D.	Section lines are correctly labeled and refer to the correct section drawing page.	X	XX	
E.	Plan drawings that span more than one drawing have sufficient overlap so specific duct or piping runs can be followed. Plan drawings should not overlap so much that there is confusion about the number of units or there are perceived redundant features.	X	XX	

6. Equipment shown on drawings is included and labeled in the schedules

Checks:

		DD	CD	S
A.	Tag numbers on equipment schedule match equipment on plan views.	X	XX	
B.	The correct quantity of specific units of each type (i.e. terminal units) is listed. This does not apply to devices that are not quantified, like diffusers, valves, etc.	X	XX	
C.	Approximate equipment location within the building and service of each piece of equipment is listed on the schedule.	X	XX	
D.	All devices that require electrical connections are labeled independently so that they can be cross-referenced between disciplines, since each device will require a separate electric feeder.	X	XX	

7. Fire/life safety and emergency power response matrices are included and complete

Checks:

		DD	CD	S
A.	A basic matrix is provided in the specifications, listing each piece of equipment and its required response to power outage.	X	XX	

		DD	CD	S
B.	Responses of the equipment in the emergency power response matrix include loss of street power and transition to emergency power, resumption of street power from emergency power, and resumption of street power from an OFF condition. System reset requirements are given, such as the need for manual reset at the equipment, reset at BAS workstation or automatic reset.	X	XX	
C.	A basic matrix is provided in the specifications, listing each piece of equipment and its required response to different types of fire alarm events.	X	XX	
D.	Responses of the equipment in the fire alarm matrix include responses by all affected equipment (fans, dampers, pumps, doors, etc.) to all the different types of trips (smoke, heat, sprinkler, tamper, general alarms, etc.).	X	XX	XX
E.	Coordinating responsibilities for the power outage and fire alarm matrix and its customization to the project, particularly the reset requirements, is assigned in the specifications. Typically this is coordinated by the commissioning provider with required input by the contractor and the design team.	X	XX	

8. System one-line, flow and riser and other needed schematic diagrams are included and complete

Checks:

		DD	CD	S
A.	All system schematics or flow diagrams use a common logic display style and common symbols, line types, etc.	X	XX	
B.	Components of the one-line drawings are not in conflict with the components shown elsewhere (i.e. details and control drawings)			
C.	Schematics that span more than one page are correctly labeled. Continuation points (match lines) are clear and logical.	X	XX	

		DD	CD	S
D.	A chilled water system one-line flow diagram is provided, including: chillers (primary and secondary loops), cooling towers, pump flow rates, pump horsepower, sensor locations, valves, and design entering and leaving water temperatures for all components (condenser and evaporator sides of the chiller, cooling towers, and heat exchangers). Representations of main loads (coils) are included. The control schematic is not appropriate to meet this requirement, except on simple systems.	X	XX	
E.	A heating water system one-line flow diagram is provided, including: boilers (primary and secondary loops), steam generators, pump flow rates, pump horsepower, sensor locations, valves, and design entering and leaving water temperatures for all components (boiler, steam generators, heat exchangers, heat recovery chillers, and buffering tanks). Representations of main loads (coils) are included. The control schematic is not appropriate to meet this requirement, except on simple systems.	X	XX	
F.	A water riser diagram by floor is included in the drawing set for chilled and heating water. Water flow quantities and main pipe sizes are shown and correct (they add up to the total provided). All pumps and valves (isolation, control and balancing) are shown.	X	XX	
G.	Floor-by-floor air riser diagrams with all supply, return and exhaust paths are shown. Air flow quantities are shown at each fan and floor and are correct (they add up to the total provided). Damper, hydronic valve and airflow configurations within each air handler are shown. All fans, fume hoods and dampers are shown, including control, fire/smoke and balancing dampers. This diagram may double as the air-side flow diagram.	X	XX	
H.	Space/room pressurization requirements are well specified. A room plan drawing or other means should be provided to communicate the requirements if they cannot be shown on air riser diagram.	X	XX	
I.	Air and pressure parameters to be determined by the balancer are clearly identified, and reporting criteria are well defined.	X	XX	

Resources

California Energy Commission. (2004) “Reference Specifications for Energy and Resource Efficiency.” California Energy Commissioning website, http://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

Energy Design Resources. (2006) “Design Briefs: Design Details.” Energy Design Resources website, http://www.energydesignresources.com/category/detailing/. Accessed Dec 2006.

Energy Design Resources. (2006) “Design Briefs: Design Review.” Energy Design Resources website, http://www.energydesignresources.com/category/detailing/. Accessed Dec 2006.

7. Specification of Requirements, Roles and Responsibilities Issues

Delineating the responsibilities in the specifications of different entities is important, so that the products installed in the building will perform as intended. The primary cause of change orders, less-than-desirable installations and sub-optimal performance is due to unclear or incomplete specifications. During design review, these issues can be mitigated by checking for conflicts and incompleteness in the specification of requirements and responsibilities. The following are requirement and responsibility issues that are often overlooked in the specifications.

Below are four categories of responsibility issues, each with a number of checks.

1. Contractor and supplier commissioning requirements included in the specifications are complete, clear and consistent.
2. Training requirements are clear and complete.
3. Contractor controls submittal requirements are clear and complete.
4. Equipment feature and installation requirements are clear.

1. Contractor and supplier commissioning requirements included in the specifications are complete, clear and consistent

Checks:

		DD	**CD**	**S**
A.	Specification clearly states the commissioning requirements and responsibilities are consistent with the owner’s project requirements. The specification is organized such that the roles and responsibilities of various supplier and subcontractors are reasonably apparent during bidding.	X	XX	
B.	Contractor commissioning responsibilities are referenced in Division 1 and in the general section of each division with commissioning responsibilities, preferably also in the technical equipment specification, particularly when the equipment supplier has commissioning responsibilities. The fact that commissioning is required is clearly stated, and reference is made to the main commissioning sections.	X	XX	
C.	Specification clearly states the commissioning and testing responsibilities of the contractors and commissioning provider for each equipment discipline (electrical, fire life safety, security, etc. vs. conventional HVAC). A check and testing responsibility matrix by equipment has been included.	X	XX	

		DD	CD	S
D.	Specification clearly states who creates construction checklist and functional and performance test forms, who reviews and approves them, who fills them in during execution and who reviews and approves them when complete. A check and testing responsibility matrix by equipment has been included.	X	XX	
E.	Specification clearly states specific requirements for controls point-to-point testing, sensor calibration and documentation.	X	XX	
F.	Specification clearly states required or allowed sampling relative to each commissioning activity (for checklists, field observation, testing, etc.).	X	XX	
G.	Specification clearly states equipment specific testing requirements, indicating acceptable test methods, operational modes, conditions and seasons required to test under. At minimum, a sample test form is included for each discipline (HVAC, electrical equipment, etc.).	X	XX	
H.	Specification clearly states trend log requirements: equipment covered, the trending objectives and performance criteria, format of trends, number of points, data logging intervals, graphs and interpretation required. Additionally, who will set up, download, graph and analyze the trends is clearly specified.	X	XX	
I.	Specification clearly states performance acceptance criteria. Examples include: space conditions (dry bulb, RH), equipment efficiency (chillers and boilers), control loop performance (e.g., control air handler discharge air temperature to +/-1.0F without hunting), control system network speed (workstation refresh rate), and other project requirements.	X	XX	
J.	Specification clearly states commissioning activities defined in pre-design or design charettes are included in contract documents (training, O&M staff participation during construction, design team roles in training, etc.).	X	XX	
K.	Specification clearly states the degree of completion of commissioning activities required for substantial completion (e.g., first round of manual testing with issue resolution identified, trending pending, all training, except deferred controls sessions, all O&M manuals, except controls as-builts, etc.). Similar for final completion.	X	XX	

2. Training requirements are clear and complete

Checks:

		DD	CD	S
A.	Specification clearly states which equipment will require staff training.	X	XX	
B.	Specification clearly states the duration of each training. Training hours sufficient, but not excessive.	X	XX	
C.	Specification clearly states the topics and scope of training. Requirements are sufficient, but not excessive.	X	XX	
D.	Specification clearly states the digital, visual or audio recording requirements (which equipment, for how long, by video professional, owner staff, contractor staff, etc.).	X	XX	
E.	Specification clearly states the requirements for documentation that should be left behind at training sessions (for example, manuals, hardcopy of PowerPoint presentations, etc.).	X	XX	

3. Contractor controls submittal requirements are clear and complete

Checks:

		DD	CD	S
A.	Control drawings submittal requirements include: network architecture, full schematic for each piece of equipment, including valves, pump and fan motor sizes and flow rates, dotted lines between controlled devices and sensor or controller, interlocks to other equipment, even if not controlled by BAS and the location of remote points off the schematic.	X	XX	XX
B.	Control drawings submittal requirements include a points list and a room schedule with terminal devices and serving air handlers.	X	XX	XX
C.	When the design engineer has not and will not provide it in the design documents, the specifications require the control contractor to write and include in the sequences of operation submittal an overview narrative briefly describing the system, components and areas served.	X	XX	XX

		DD	CD	S
D.	Control sequences of operation submittal requirements include: enhancing the designer's sequences to include all of the following detail that is missing, incomplete or inaccurate: Equipment starting and stopping, staging up and down, capacity control, resets, lockouts, deadband intervals, delays, interlocks, loss of power results, power reset requirements, equipment failure and standby response, all equipment and specified control features, low load and off season operation, delineation of control and monitoring for interfaces with packaged equipment.	X	XX	XX

4. Equipment feature and installation requirements are clear

Checks:

		DD	CD	S
A.	Equipment features included in the Owner's Project Requirements are clearly listed in the equipment specifications.	X	XX	
B.	Clearly document which points are passed from packaged equipment to the building automation system (BAS) for monitoring or control and which parts of the sequences are controlled by the package equipment or the BAS. Document whether sensors are provided by the BAS contractor or the equipment contractor.	X	XX	XX
C.	Document who provides, programs and starts up all VFD's.	X	XX	XX
D.	Equipment or system warranty start dates are well defined. Review and request clarification if warranties begin at start-up, acceptance, occupancy or other milestones. Review how warranties may be extended if issues remain past the warranty period. Pay special attention to seasonal equipment/systems.	X	XX	XX

Resources

ASHRAE. (2005) *The Commissioning Process*. ASHRAE Guideline 0-2005.

ASHRAE. (2007) *The HVAC Commissioning Process*. ASHRAE Guideline 1-2007.

California Energy Commission. (2004) "Reference Specifications for Energy and Resource Efficiency." California Energy Commissioning website, http://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

Energy Design Resources. (2006) "Online Tools: Commissioning Assistant." Energy Design Resources website, http://www.energydesignresources.com/resource/176/. Accessed Dec 2006.

8. Test Port and Gauge Issues

Test ports and gauges allow for initial set up and adjustment, commissioning and troubleshooting. Significant time and effort spent looking for unforeseen problems during start-up and later on during the life of the building can be avoided if test ports and gauges are located in critical locations. Expense can be avoided by requiring test ports and gauges in the contract documents rather than specifying and installing them after the fact. The following issues relating to test ports and gauges are often overlooked in the drawings and specifications.

Below are two categories of test port and gauge issues, each with a number of checks.

1. Requirements for test ports for temperature and pressure, temperature wells and pressure gauge manifolds are provided.
2. Requirements for service outlets such as drain and hose valves and power outlets near mechanical units are provided.

1. Requirements for test ports for temperature and pressure, temperature wells and pressure gauge manifolds are provided

Checks:

		DD	CD	S
A.	Pressure and temperature (P/T) test ports (“Pete’s Plugs”) are shown across all major equipment (pumps, chillers, boilers).	X	XX	XX
B.	On pumps, only one pressure gauge is installed across the pump (with needed shutoff valves for reading suction and discharge pressures). Tubing is tapped into pump flanges, not two gauges and not tapped down stream or upstream on piping. The line is extended and taps in past the inlet strainer allowing strainer pressure drop to be measured with the same gauge.	X	XX	
C.	P/T ports are shown on chiller for entering and leaving water of both condensers and evaporators as close to the barrels as possible and before any elbows, so accurate flow correlations can be made with manufacturer data.	X	XX	XX
D.	P/T ports are shown near contractor installed sensors so handheld readings can be taken for field calibration. Ports should be up or down stream of sensor sufficiently close to allow an accurate comparison with the sensor.	X	XX	XX
E.	P/T ports are shown before and after each coil, control valve and on both sides of 3 inch and larger strainers.	X	XX	XX

		DD	CD	S
F.	Test ports, temperature and pressure wells, and taps are shown on details, schematics and plan views (i.e. coil piping and pump details).	X	XX	XX
G.	P/T ports show extensions through pipe insulation.	X	XX	
H.	Liquid, bi-metal or digital thermometers are shown in the return and supply of all primary thermal plant equipment (chillers, cooling towers, boilers, converters, etc.).	X	XX	XX

2. Requirements for service outlets such as drain and hose valves and power outlets near mechanical units are provided

Checks:

		DD	CD	S
A.	All mechanical rooms with equipment that requires draining have a hose and end drain valve and floor drain receptor. Ensure hazardous materials are drained to proper waste systems.	X	XX	XX
B.	Cooling tower areas have a hose drain valve for cleaning purposes (freeze-proof when required).	X	XX	XX
C.	Accessible power outlet locations and criteria are shown in specifications and on the drawings.	X	XX	
D.	Emergency power and lighting requirements for critical equipment are listed and shown in specifications and drawings.	X	XX	
E.	Low point drains on piping systems have an available drain or means of fluid disposal.	X	XX	

Resources

ASHRAE. (2003) “Testing, Adjusting and Balancing,” *ASHRAE HVAC Applications*.

Avery, Gil. (1993) “Design and Commissioning Variable Flow Hydronic Systems,” *ASHRAE Journal*. July 2003.

California Energy Commission. (2004) “Reference Specifications for Energy and Resource Efficiency.” California Energy Commissioning website, http://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

National Environmental Balancing Bureau. (2005) *Design Phase Commissioning Handbook.*

Taylor, S.T. (2002) “Balancing Variable Flow Hydronic Systems,” *ASHRAE Journal*. October 2002.

9. Energy Efficiency Issues

Good design practice dictates that attention is paid to the energy efficiency of each system even if it is not explicitly included in an owner's project requirements. Simply considering this factor early in the design can result in dramatic reductions in operating costs at a minimal incremental cost. Although developing energy efficient designs is the responsibility of the designers, proper review of the energy features in the design will aid in optimizing performance at the design phase when making changes and adjustment is least costly.

Below are twelve areas that when covered in design reviews can significantly improve energy efficiency.

1. Issues of equipment sizing and control capabilities are properly addressed
2. Air handler economizer and outside air control no cost / low cost energy efficiency features are utilized
3. Air handler duct static pressure and supply air temperature control no cost / low cost energy efficiency features are utilized
4. Other air handler no cost / low cost energy efficiency features are utilized
5. Air handler moderate-cost or more involved system energy efficiency features are utilized
6. VAV air terminal unit incorporates energy saving concepts
7. Heating water plant incorporates energy saving concepts
8. No-cost/low-cost chilled water energy efficiency measures are utilized
9. Moderate-cost or more involved chilled water energy efficiency measures are utilized
10. Hydronic piping and pumping system utilizes energy saving concepts (chilled, condenser and heating water)
11. Lighting systems utilize energy savings concepts
12. Motor driven systems are optimized.

1. Issues of equipment sizing and control capabilities are properly addressed

Checks:

		DD	CD	S
A.	For moderately sized and larger buildings, a simulation tool was used to understand the part-load performance and operating costs of system alternatives.	XX		

		DD	CD	S
B.	To ensure proper sizing and minimize oversizing, heating and cooling load calculations were performed using an ASHRAE Fundamentals-based methodology (ACCA Manual N Commercial Load Calculation, DOE-2 or other simulation program, etc.). Excessive safety factors were not used. Question the designer if the plug load used in the load calculations exceeded 1W/sf.	XX	XX	
C.	The heating and cooling central plant equipment is designed to handle the smallest expected load efficiently. The design avoids excessive cycling and inefficient techniques like hot gas bypass/reinjection.	XX	XX	
D.	Computer or data center room air conditioning units will not cause the central chilled water system to run at very low loads for a significant portion of the winter. More appropriate solutions such as a remote air-cooled chiller, DX condensers, etc. are used.	XX	XX	
E.	The level of complexity for the systems and controls, and the level of interaction required by the operators, are consistent with their expected level of knowledge and training.	X	XX	
F.	All energy conserving BAS features are specified to be “set up and operating,” rather than just stating that the BAS “shall be capable of…” Requirements for troubleshooting, documentation, and training are also provided, as applicable.	X	XX	XX

2. Air handler economizer and outside air control no cost / low cost energy efficiency features are utilized

Checks:

		DD	CD	S
A.	Economizer types comply with ASHRAE 90.1 and/or California Title 24, depending on the climate. Where permitted on larger air handlers, comparative or differential, not fixed or single point, enthalpy types are used. In dry climates, fixed enthalpy types are not used. In hot and humid climates, dry bulb types are not used. Because of sensor inaccuracies in less expensive equipment, single point enthalpy (A, B, C, D setting) economizers are not used in small rooftop packaged units, rather use a dry bulb comparative type.	X	XX	

		DD	CD	S
B.	Economizers are integrated with mechanical cooling when required by ASHRAE 90.1 and/or California Title 24 by climate and otherwise when they will cost-effectively save energy (larger number of hours of integrated operation) and will not result in coil freeze-up in very cold weather.	XX	XX	XX
C.	Factory-installed, and ideally factory run-tested, economizers are specified in rooftop packaged equipment. Distributor or field installed economizers are not acceptable.	X	XX	XX
D.	Economizer dampers are specified to be driven by direct drive actuators rather than rod linkages, which can be a major cause of economizer malfunction.	X	XX	XX
E.	Minimum outside air control is optimized. See the Design Review checks for Outdoor Air Control.	X	XX	
F.	Barometric relief is used, if possible. If not, relief fans are used (rather than return fans) in most cases.	X	XX	

3. Air handler duct static pressure and supply air temperature control no cost / low cost energy efficiency features are utilized

Checks:

		DD	CD	S
A.	Ducts utilize low static pressure design. See the Design Review checks on Duct System Issues.	XX	XX	
B.	The mixed air temperature setpoint, when used, is set to equal the supply air temperature set point less a few degrees for fan heat. If it is set lower, reheat energy will be wasted; if higher, cooling energy will be wasted.	X	XX	
C.	In systems with return dampers, alternatives to conventional interlocked inverse control of the return air damper (RAD) and outside air damper (OAD) are considered to reduce fan energy. One such strategy is leaving the RAD fully open as the OAD modulates open to economize. Once the OAD is fully open and supply temperature cannot be met, the RAD modulates closed.	X	XX	

		DD	CD	S
D.	The supply air temperature (SAT) setpoint is reset on appropriate parameters, such as the combination of outside air temperature and terminal box cooling demand. SAT is reset to minimize reheat during cool weather and reduce chiller operation during warm weather.	X	XX	
E.	A requirement is provided for the parameters used in the SAT reset algorithm to be user adjustable from the workstation.	X	XX	
F.	SAT resets off terminal box or valve demand should not rely on a lone worst device, but average a few worst devices, lest one bad device drive the entire system. The current worst devices are identified on the operator’s workstation.	X	XX	
G.	Special attention has been paid to SAT reset when used in hot and humid climates or when there are special dehumidification needs. In such cases, the reset parameters are carefully chosen and the reset is discontinued when the humidity in the return air reaches a threshold.	X	XX	
H.	SAT reset is coordinated with duct static pressure reset, with priority given to the reset that will save more energy	X	XX	
I.	In variable air volume systems, duct static pressure is reset to meet the requirements of only the zone requiring the most pressure (air terminal box with most open damper).	X	XX	
J.	In variable air volume systems where duct static pressure is not reset, the fixed set point is specified to be set at the lowest possible value that will satisfy about an 85% diversity of the air terminal boxes fully open. The controlling pressure sensor is located ¾ the way from the fan to the last terminal unit on the hydraulically longest duct run. The balancing and control procedure for determining the appropriate setpoint is clearly specified.	X	XX	

4. Other air handler miscellaneous no cost / low cost energy efficiency features are utilized

Checks:

		DD	CD	S
A.	Fans appear to be correctly sized for application, accounting for a factor of safety, diversity and redundancy issues. The results of a quick cfm per square foot calculation appear reasonable. Calculations greater than 0.9 cfm/sf in a conventional office VAV system and more than 0.7 cfm/sf in under floor air distribution systems should be questioned.	XX	XX	
B.	Both optimum start and optimum stop are incorporated.	X	XX	
C.	Night set back and set up are incorporated.	X	XX	
D.	Pre-filters are omitted unless specially needed, and a requirement is provided to change final filters.	XX	XX	XX
E.	Commercial grade two-stage cooling thermostats with the capability to schedule fan operation and heating and cooling set points independently are specified, for single zone packaged or split system air handlers.	X	XX	XX
F.	Thermostatic expansion valves (TXVs) are specified, rather than fixed-orifice types, in roof top DX units. TXVs make units more tolerant to refrigerant charge variations by maintaining unit efficiency over a wide range of under-or over-charged conditions.	X	XX	XX

5. Air handler moderate-cost or more involved system energy efficiency features are utilized

Checks:

		DD	CD	S
A.	Supply and return air shafts are coordinated and appear to be optimized. Multiple air shafts are used for large floor plates.	XX		
B.	With large built-up air handlers, air shafts are placed near, but not directly under, the air handling units (to minimize fan discharge system effects). With rooftop equipment, utilize downward discharge fans and locate ductwork immediately under the unit.	XX		

		DD	CD	S
C.	Demand controlled ventilation is used for areas with occupancies more dense than 40 square feet per person, and/or in zones with occupancy rates that vary significantly over the day.	XX	XX	
D.	Fan type specified is housed airfoil when possible.	XX	XX	XX
E.	The design accommodates partial occupancy energy savings when the owner's requirements or narrative describe the possibility of partial occupancy. This is accomplished by zoning air handlers by floor or part of a floor, by incorporating controlled floor dampers, or closing VAV air terminals when not occupied, etc.	XX	XX	
F.	Each air handler is zoned to serve only areas with common loads by time of day. For example, interior zones are grouped, and areas with perimeters facing the same direction (for smaller buildings combine West and North) are grouped to allow more aggressive control and reset strategies.	XX	XX	
G.	Variable air volume air handlers are used when the air flow needs vary over time.	XX	XX	
H.	When possible, split-system DX equipment outdoor units are located in shaded areas or provided with screening to shade the unit from solar heat gain.	XX	XX	
I.	Requirements are provided to adjust fan sheaves if throttling more than 20 percent is required to meet design for non-VFD controlled motors over 5 hp. For fans greater than 20 hp controlled by VFDs, there is a requirement that fan sheaves be replaced (rather than using the VFD to reduce flow) if more than 30% throttling is required at design loads. Specifications indicate this will be a requirement to evaluate, but costs for any required changes will be covered by a change order.	X	XX	
J.	Heat recovery is specified on 100% OA systems: heat pipe, heat wheel, or runaround.	XX	XX	
K.	Extended surface filters are specified in air handlers that can accommodate them. Although more expensive, they have higher dust holding capacity, longer life and lower pressure drop.	XX	XX	XX
L.	Coil face velocity is less than 500 fpm (ideally 400 fpm), and the coils are the largest that can reasonably fit in the allocated space.	XX	XX	
M.	Heating and cooling coil fin spacing densities are less than 12 fins/inch to minimize dirt build-up and pressure drop.	X	XX	XX

		DD	CD	S
N.	A bypass with damper were considered between the coil sections of a large built-up AHU where the intermediate coil headers are located (the space is already allocated for piping). The bypass is open except when the coil valve is open. Airfoil damper blades, rather than the typical v-groove blades, are used for velocities over 1500 fpm, to reduce fan pressure drop, and save fan energy.	XX	XX	XX
O.	For DX air handlers with water-cooled condensers, the entering condenser water temperature is reset based on outdoor wet bulb or surrogate conditions. See cooling tower control under Low-Cost Chilled Water measures.	X	XX	XX
P.	In drier climates and when large outdoor air fractions are required, evaporative pre-cooling packages were considered in which outside air is pre-cooled, the air flowing over the DX condensing unit is cooled, and pre-cooled air is dehumidified across the unitary cooling coil.	XX	XX	
Q.	In semi-arid climates, two-stage evaporative cooling has been evaluated as an alternative to mechanical refrigeration.	XX	XX	
R.	Night flushing has been considered in dry climates when exposed masonry, including underside of floor slabs in above ceiling return plenums, is at least equal to the floor area. This can be particularly beneficial where off-peak electrical rates are much cheaper than on-peak. A typical control sequence is to flush with 100% outside air (OA) when the next morning is likely to require more cooling than reheat energy, and when OA is at least 7°F cooler than the inside. The flush occurs until the inside is within 3°F of the outside or 65°F.	XX	XX	

6. VAV air terminal unit incorporates energy saving concepts

Checks:

		DD	CD	S
A.	No-fan powered boxes are used, unless necessary. If fan powered boxes are needed, parallel boxes rather than series are used.	XX	XX	

		DD	CD	S
B.	The VAV box utilizes a "dual maximum" control logic which uses a cooling minimum cfm setpoint equal to the larger of the following: the minimum where the box can still provide stable control, and the minimum required to maintain the minimum ventilation rate. This will usually be lower than the typical non-dual max heating set point. The heating has two set points—min and max, with the maximum being near the typical non-dual max heating set point. (Advanced VAV System Design Guide, CEC 2003, p. 59)	X	XX	
C.	The VAV box minimum airflow set point is set to the larger of the following: the lowest controllable airflow set point allowed by the box or the minimum ventilation requirement (normally 0.15 cfm/sf).	XX	XX	
D.	All VAV boxes are sized for a pressure drop very near 0.5 inches WC (including reheat coil), except for very noise-sensitive locations. To balance pressure drop energy and minimum flow set point limitations, oversized boxes cannot turn down as much and undersized boxes waste fan energy.	XX	XX	
E.	Interior zone air flows are sized so the expected peak loads can be met at air temperatures higher than the minimum design temperature. This allows supply air temperature to have a higher reset and reduces the reheat that is necessary in perimeter zones when satisfying cooling needs of interior zones.	XX	X	
F.	Conference rooms use CO_2 demand controlled ventilation to reset the minimum airflow, or use a series fan powered box with a zero minimum airflow set point, where the box will shut off when unoccupied.	XX	XX	
G.	To facilitate partial occupancy energy savings, the specifications require or drawings show that the VAV boxes are divided into "isolation" areas if the owner's requirements or narrative describe any possibility of partial occupancy. Specifications state that these isolation areas will have their own time of day schedules, setbacks, set points, etc. All boxes can be commanded or scheduled totally shut together.	XX	XX	

7. Heating water plant incorporates energy saving concepts

Checks:

		DD	CD	S
A.	Boilers are high efficiency condensing type.	XX	XX	XX

		DD	CD	S
B.	Heating water system utilizes low return water temperatures to increase boiler efficiency, and heating water coils are correspondingly "oversized".	XX	XX	
C.	Boiler staging control is incorporated to take advantage of boiler part load efficiencies and to optimize total plant efficiency.	XX	XX	XX
D.	Combustion air blowers are variable speed.	X	XX	
E.	Automatic oxygen trim controls are used.	X	XX	
F.	Stack economizers or combustion air pre-heaters are utilized on steam boilers.	X	XX	
G.	Continuous blowdown heat recovery is incorporated on steam boilers.	X	XX	

8. No-cost/low-cost chilled water energy efficiency measures are utilized

Checks:

		DD	CD	S
A.	Cooling tower staging and fan speed are controlled either: 1) directly from a chiller condenser head pressure reference set point, or 2) from a tower leaving water temperature that is reset based on a head pressure reference, the outdoor air wet bulb and tower approach, or a surrogate for wet bulb from a regression of local mean coincident wet bulb vs. dry bulb.	X	XX	
B.	Variable flow condenser loop control, if used, is based on a chiller condenser head pressure reference. This is more effective in systems with a moderate delta-T (10ºF to 12ºF) than in high delta-T systems.	X	XX	
C.	Optimum chiller stop is incorporated, which utilizes water in the chilled water loop for at least the last 30 minutes of operation for the day.	X	XX	
D.	Chilled water temperature is reset based on return water temperature or zone demand. Special attention is paid to dehumidification requirements and making sure chiller savings are not offset by pump energy.	X	XX	
E.	Chillers of different sizes are used so a smaller chiller can run during low loads. Controls are provided to sequence the chillers to match the load.	XX	XX	

		DD	CD	S
F.	Multiple cooling tower fans are run on low speed rather than a single fan at high speed. Fan staging is optimized by: 1) running condenser water over all towers with fans off 2) starting all fans on low speed 3) ramping all fans up together	X	XX	
G.	The condenser water flowrate for any tower will never go below one-half of its design flowrate without checking with manufacturer first, and will generally never go below two-thirds of its design flowrate, unless hot deck (top) weir dams and special nozzles are specified. The tower fans will never operate at full speed without at least 50% of design water flow.			

9. Moderate-cost or more involved chilled water energy efficiency measures are utilized

Checks:

		DD	CD	S
A.	Variable primary chilled water evaporator flow is used or was considered.	XX	XX	
B.	A chiller with a variable-speed compressor is used or was considered.	XX	XX	
C.	Chillers are sequenced optimally, taking into consideration the current load and partial load efficiencies of chillers.	XX	XX	XX
D.	A total kW/ton efficiency calculation is performed for each operating condition. Condenser water temperature, chilled water temperature and chiller staging are optimized at each condition.	XX	XX	XX
E.	An oversized cooling tower or a low approach tower capacity is incorporated.	XX	XX	
F.	Heat recovery chillers or bundles are incorporated for domestic hot water, low temperature heating water for space heating, or outdoor air pre-heating. Heating coils are designed for lower temperature water.	XX	XX	
G.	A higher condenser water delta-T design is used (12ºF to 18ºF rather than the conventional 10ºF) or was considered. The cooling tower is oversized accordingly.	XX	XX	

		DD	CD	S
H.	A higher evaporator water delta-T design is used (12ºF to 20ºF rather than the conventional 10ºF) or was considered. The air handler chilled water coils are designed accordingly.	XX	XX	
I.	Demand limiting procedures are incorporated or were considered.	XX	XX	
J.	Steam and gas absorption chillers are used if a cost-effectiveness analysis shows they are advantageous.	XX	XX	
K.	Gas engine- and steam turbine-driven centrifugal chillers are used if a cost-effectiveness analysis shows they are advantageous.	XX	XX	
L.	When cool weather cooling loads cannot be met by 100% outside air economizing, a plate and frame heat exchanger is used in parallel with the chiller to chill the water directly from the cooling tower water.	XX	XX	

10. Hydronic piping and pumping system utilizes energy saving concepts (chilled, condenser and heating water)

Checks:

		DD	CD	S
A.	Hydronic loop pressure is reset based on heating or cooling water valve positions for the valves in most demand. A typical sequence would be to reset the differential pressure set point until two valves are at least 90% open. Using two valves, rather than one, reduces the chance that a rogue zone (e.g., where the thermostat is located above a copying machine) will drive the set point, inappropriately.	X	XX	
B.	In variable flow systems, there are no 3-way valves. The only exception should be for a valve with an opening limit or a balanced bypass line that is sized for the lowest flowrate at which the pump can operate without overheating. Sequences of operations show that this valve is to be opened only after all coil valves are closed.	XX	XX	
C.	Long radius elbows are utilized if space permits, and piping offsets are in only two dimensions. Avoid three changes of direction in same area.	X	XX	

		DD	CD	S
D.	When a T splits flow, the largest percentage of flow goes through the "run" as opposed to the "branch". When a T combines flow, the combined flow should leave through a "run" and not the "branch". Manufactured tees are specified in place of saddle joints.	X	XX	
E.	Pumps are not oversized. The capacity of each pump does not exceed the sum of the coil capacities served. No additional safety factor is needed, since the normal coil load diversity provides the pump safety factor.	X	XX	
F.	Requirements are provided to trim pump impellers, if throttling more than 20 percent is required to meet design, for non-VFD controlled motors over 5 hp. For pumps greater than 20 hp controlled by VFDs, there is a requirement that pump impellers be trimmed, rather than use the VFD to reduce flow, if more than 30% throttling is required at design loads Specifications indicate this will be a requirement to evaluate, but costs for any required changes will be covered by a change order.	X	XX	
G.	For the cooling tower bypass, a 2-way valve in the bypass line rather than a 3-way valve is used, in order to reduce pressure drop. The 2-way valve is sized so that no water will go over the tower when in full bypass.	X	XX	

11. Lighting systems utilize energy savings concepts

Checks:

		DD	CD	S
A.	The design utilizes lighting occupancy sensors in appropriate locations, such as conference rooms, enclosed offices, restrooms and storage rooms. Appropriate types are used, such as ultrasonic for restrooms. Sensors are located appropriately so that they will not be affected by passers-by through open doors, door sidelights and exterior windows, etc.	X	XX	XX
B.	Lighting occupancy sensors tie into the air terminal units and close terminal dampers when the space is not occupied, if this meets design intent. In such cases, unoccupied low and high limit controls are provided for perimeter zones.	X	XX	XX
C.	Scheduled lighting controls and sweeps are utilized.	X	XX	XX

		DD	CD	S
D.	Day-light dimming utilization is incorporated and maximized. Skylights, transom (split high) glazing and light shelves utilized as design intent allows. See the Design Review checks for Daylight Dimming.	XX	XX	XX
E.	Exterior lighting controls are utilized with photocell-based and schedule-based operation.	X	XX	XX

12. Motor driven systems are optimized

Checks:

		DD	CD	S
A.	Requirements are included for the voltage at the motor to be kept as close to the nameplate value as possible, with a maximum deviation of 5%. Large variations significantly reduce efficiency, power factor, and service life.	XX	XX	
B.	Specifications require that the voltage of each phase in a three-phase system be balanced to within 10% of each other.	X	XX	
C.	The design indicates that a power quality study was conducted and that the design utilizes power factor correction, as appropriate.	X	XX	
D.	Efficient and properly sized step-down transformers are specified.	X	XX	
E.	Power cables that supply motors expected to run near full load for many hours are oversized, minimizing line losses and voltage drops.	X	XX	
F.	Sequences of operation call for motors to be turned off or at minimum speed when not needed.	X	XX	
G.	Adjustable speed drives or two-speed motors are utilized where appropriate.	XX	XX	
H.	Energy efficient motors are specified.	X	XX	XX
I.	Motors are sized to match load. Motors are sized to run primarily in the 65% to 100% load range.	X	XX	
J.	The design takes advantage of synchronous belts, cogged belts or chains in place of V-belts when possible, to reduce slip.	X	XX	
K.	The design will ensure that correct motor temperature is maintained. This includes making sure that motors are shaded from sun and well ventilated.	X	XX	

Resources

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U.S. Department of Energy. "Optimizing Your Motor-Driven System." U.S. Department of Energy's Energy Efficiency and Renewable Energy website, http://www1.eere.energy.gov/industry/bestpractices/pdfs/mc-0381.pdf. Accessed Dec 2006.

10. Air and Water Balancing Issues

Proper air and water balancing are essential for proper functioning of HVAC systems, ensuring that they maintain comfort and air quality in the most energy efficient manner possible. Technically sound and transparent design, combined with clear instructions to the air balancing contractor are needed, but they are not always found in design documents. Too often the contractor, because of insufficient information, makes improper decisions in the field or unneeded requests for information, and change orders are needed to properly balance the system.

Below are four categories of balancing issues, each with a number of checks.

1. Drawings and specifications are coordinated and contain sufficient technical data
2. Flow and riser diagrams for major systems (chilled water, heating water, and air) are included
3. Sufficient and appropriate balancing dampers or valves are shown in drawings and in the specifications
4. Balancing requirements are complete and clear

1. Drawings and specifications are coordinated and contain sufficient technical data

Checks:

		DD	**CD**	**S**
A.	Specific minimum outside air quantities and set up parameters are shown on drawings (e.g., set air quantity with 75% of air terminal boxes in heating). See Design Area 14 Outdoor Air Issues.	X	XX	
B.	The diversity factor for air and hydronic flows is determined from review of the equipment schedules and matches the design intent obtained from the designer.	XX	XX	
C.	Air flow quantities on the mechanical floor plans correlate with the totals in the equipment schedules. For example, if the floor diffusers totaled 30,000 cfm and assuming 5% duct leakage, 5% reasonable safety factor, and 85% as a reasonable diversity factor, then the equipment schedule should show the fan to be 28,100 cfm (30,000 x 1.05 x 1.05 x 0.85).	X	XX	
D.	The sequences of operation will work with the piping and valve layout (e.g., bypass leg in primary / secondary systems, proper isolation in common header systems and overflow of primary chiller loops). This can be verified from review of the flow schematic and flow rates.	X	XX	

2. Flow and riser diagrams for major systems (chilled water, heating water, and air) are included

Checks:

		DD	CD	S
A.	Single line flow diagrams are shown in the drawings for major systems including the chilled water, heating water and the typical air side (supply, return, outside air and exhaust air). These diagrams include the complete path of air or water through the system with fans, coils, dampers, pumps, valves, flow rates, and sensors shown. See Review Area 6 Clarity and Detail of Contract Documents for a definition of flow diagrams vs. riser diagrams.	XX	XX	
B.	Air and water riser and balance diagrams are shown in the drawings for major systems like the chilled water, heating water and the air-side (outside, supply, return, and exhaust air balance should be shown). See Review Area 6 Clarity and Detail of Contract Documents for a definition of flow diagrams vs. riser diagrams.	XX	XX	

3. Sufficient and appropriate balancing dampers or valves are shown in drawings and in the specifications

Checks:

		DD	CD	S
A.	In constant flow hydronic loops, hydronic balancing valves are shown at: each non-VFD controlled pump, major zone or floor branch takeoffs, parallel cooling towers and chillers that are not symmetrically piped or are different sizes and at all coils. Specifications require marking or setting set screws at final valve positions. Requirements should also be found in the specifications.	X	XX	

		DD	CD	S
B.	In variable flow hydronic loops, balancing valves are only shown where actually needed. Current state-of-the-art applications recommend (debatably) that balancing valves (including auto-flow) are only needed at coils with two position (not two-way) valves. In larger systems with many branches (i.e. high rise buildings) balancing valves may also be needed at the branch takeoffs to the first few branches nearest the pump to prevent over pressurizing those branches (noise and valve erosion). These recommendations apply when the variance in pressure drop across the different coils is small, otherwise coil balancing valves may be needed. Fewer balancing valves mean lower first cost, balancing labor and pump energy. See Review Area 16 Pump, Piping and Plant Issues for recommendations against auto-flow valves in these situations. Specifications require marking or setting set screws at final valve positions. Requirements should also be found in the specifications.	X	XX	
C.	In constant volume air systems, air volume dampers are shown for each major supply and return branch (i.e. floor takeoff), for each branch serving three or more openings, for each supply opening, and for each ducted return register or grill. Requirements should also be found in the specifications.	X	XX	
D.	In variable air volume systems, volume dampers are shown for each supply air opening (except on single opening terminal units), for each ducted return register or grill, for each branch serving three or more return openings, and for each return air main branch (i.e. from a floor into a return air shaft or plenum). Requirements should also be found in the specifications.	X	XX	
E.	Balancing dampers are located at least two duct diameters away (preferably 10 or more) from supply diffusers or return registers to prevent noise. Balancing dampers are not mounted directly behind return registers that open directly into return ducts or shafts as they can be noisy and won't stay positioned.	X	XX	
F.	Balancing dampers are specified or shown to have locking quadrants and are required to be locked and marked at their final balanced position.	X	XX	

		DD	CD	S
G.	Balancing valves are sized for the flow rate, not the line size (i.e. sized to be nearly full open at design flow rate) because flow accuracy drops substantially as the valve is squeezed down.	X	XX	XX

4. Balancing requirements are complete and clear

Checks:

		DD	CD	S
A.	Requirements for the balancing report are reasonable, and correlate with actual balancing requirements (e.g., they include only the data the balancer is obligated to gather, as listed in the execution articles of the specification).	X	XX	
B.	There is language obligating the contractor to assist the balancer, if the balancer is hired directly by the Owner.	X	XX	
C.	Appropriate balancing agenda or plan requirements are included. This agenda includes, but is not limited to, report of construction documents review, specific methods for balancing each system, methods for establishing total air flow and minimum air damper position and flow, procedure for establishing set points and reset limits, building static pressure fine tuning, a complete list / outline of measurements to be taken on each piece of equipment, etc.	X	XX	
D.	Balancing contractor is required to identify the minimum pressure set points, representing the lowest possible duct and hydronic pressures needed to satisfy the zones at maximum capacity, less documented diversity.	X	XX	
E.	Balancing contractor is required to submit field notes at least once a week.	X	XX	
F.	Balancing contractor is required to submit the draft field version of the balancing report within 2 days of completing each major section of the building (i.e. each major piece of equipment, or floor) to aid in verifying that proper balancing procedures are being used and to inform functional testing.	X	XX	

		DD	CD	S
G.	There are pump impeller trim and fan sheaving requirements for non-VFD controlled motors over 5 hp, if throttling more than 20 percent is required to meet design. For motors greater than 20 hp controlled by VFD's, if more than 30% throttling is required at design loads, the contractor shall sheave the fan or trim the pump impeller. Costs for fan sheaving materials and labor shall be born by the Contractor. Impeller trim materials and labor shall be a change order. Trims are needed on VFD's because VFD's have inefficiencies at lower speeds (11% loss at 70% speed).	X	XX	
H.	Required balancing tolerances can be obtained with standard balancing equipment (i.e. standard equipment cannot obtain ± 5% at low airflow rates, below 300 CFM), unless the increased accuracy is warranted.	X	XX	

Resources

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11. Underfloor Air Distribution Issues

One of the driving forces behind adoption of underfloor air distribution (UFAD) is the assumption that the design will cause air to stratify in open office areas, resulting in improved comfort and energy savings. Currently the road towards this goal is fraught with pitfalls that need to be addressed during the design phase of a project. Relying on the construction team to work out the challenges as they occur may result in comfort and energy savings goals that are never realized. Anticipating construction issues and providing clear and complete construction documents will minimize RFI's and rework and should result in a successful project.

Below are ten UFAD issues frequently encountered in design reviews:

1. Air sealing details are effective and clear.
2. Trade responsibilities are clear.
3. Construction sequencing protocol is sufficiently specified to build systems successfully.
4. Control methods and allowable field adjustments are sufficiently prescribed in the design.
5. Balancing requirements are complete.
6. Performance and performance testing requirements are adequate.
7. Good UFAD design practice is being followed.
8. Facility staff and occupant education and training requirements are included.
9. Underfloor cleanliness coordination requirements are clear.
10. Basis of design is adequately documented and available to the construction team.

1. Air sealing details are effective and clear

A common error in specifying UFAD systems is the lack of a fully-coordinated effort between the architect and the mechanical and structural engineers when detailing the construction of the raised floor area. Generally in the UFAD system, the construction of the raised floor area is not detailed by the mechanical engineer (Division 15), but more often by the architect and structural engineer. Because of this, pressurization-related requirements may be insufficiently specified or coordinated in the design details.

Checks:

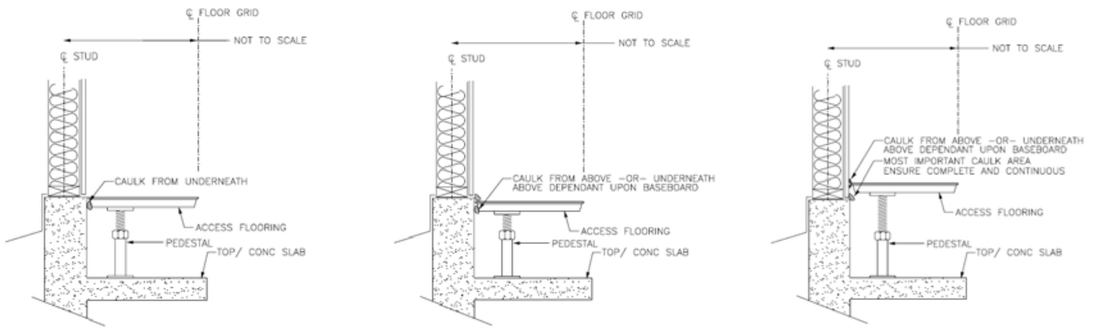
		DD	**CD**	**S**
A.	All details (arch., struc. and mech.) relating to areas of pressurization actually show the sealing method required for the specific instance. More critical sealing areas show sealing "with the pressure," not against it (like sealing a boat).		XX	

		DD	CD	S
B.	All space temperature sensors in walls are sealed from any communication with wall cavity air (even when walls are sealed at their perimeter). This requires the J-box to be sealed on its outside or inside and the box edge to be sealed to the sheet rock. This includes sealing the wiring to the inside of control conduits (where wire enters or exits the conduit) that come up from pressurized underfloor areas.		XX	
C.	Each opening between the underfloor space and a wall or floor cavity or to other spaces or zones is necessary and all openings that should not be communicating to the underfloor space are sealed.		XX	
D.	Requirements are included for the underfloor perimeter along exterior walls and above unconditioned spaces to be sealed absolutely airtight (drywall or sheet metal to concrete deck, vertical and horizontal drywall joints, other penetrations). Requirements are included for caulking of any overlapping or butting building elements used as a seals.		XX	
E.	Requirements are included for any penetrations from underfloor space into interior walls to be sealed reasonably airtight, as well as caulked (drywall to concrete deck, vertical and horizontal drywall joints, around duct, pipe, conduit, and cabling penetrations). Requirements are included for all framed walls extending below the raised floor to be sheet rocked and sealed.		XX	
F.	Requirements are included for open ends of conduits in underfloor space to be sealed with caulk.		XX	
G.	Requirements are included for penetrations of ducts and piping and other assemblies through the concrete subfloor or through the raised floor to be sealed.		XX	
H.	Requirements are included for raised floor panels butting finished walls to be gasketed and sealed reasonably tight.		XX	
I.	Requirements are included for mock-up and pressure/leak testing prior to all floors being installed, for any complex or not well understood cases.	X	XX	

***Additional Information*:**

Sealing requirements listed primarily in the specifications, even when detailed, may not provide the contractor a sufficient understanding of how to accomplish a satisfactory seal. Architectural, structural and mechanical drawing details with regard to wall joints, wall penetrations, window and door installations, stair details, transitions, and actual raised floor systems and installations must be included in the design package. With a focus on air pressurization and sealing required to maintain that pressurization, ensure that existing details are specific and point out or suggest additional details and sealing techniques to maximize the understanding of the critical nature of this plenum.

Typical Details



2. Trade responsibilities are clear

The design and specification requirements for UFAD systems plenums must be directed to trades in addition to mechanical. However, specifications often don't delineate which trade is responsible for what task (such as air sealing and cleaning), and as a result some tasks are not completed.

Checks:

		DD	CD	S
A.	Sealing requirements are found in each trade's respective specification section. This is assessed by reviewing each sealing and cleaning detail and requirement, identifying the trade responsible to do the work, and reviewing that specification section.	XX	XX	
B.	Most or all of the sealing and cleaning requirements are located in Division 1, if they are mostly in one section, and the divisions of all responsible trades refer to that section. Articles too spread out result in missing requirements.	XX	XX	
C.	Requirements are included for accessibility and spatial clearances around underfloor terminal devices.	XX	XX	

3. There is sufficient construction sequencing protocol to build systems successfully

Successful UFAD projects require careful sequencing of different trades performing tasks and installing systems that may be new to them. Some tasks just cannot be successfully accomplished if not completed at the proper time. For example, after perimeter furnishings are installed, underfloor areas cannot be sealed. It is imperative that the contractor carefully plan the multi-trade effort of installing a UFAD system. Though there may be an optimal sequence, specifying it may not be appropriate. Until the process becomes more common, requiring a plan from the contractor is warranted.

Check:

		DD	CD	S
A.	Requirements are included for the contractor to submit a sequencing plan that identifies major areas and types of underfloor air sealing and cleaning. The plan notes the sequence in which each task will be accomplished and the individuals responsible for their completion and inspection.	X	XX	XX
B.	Requirements are included for detailed multi-discipline shop coordination drawings of the underfloor space.	X	XX	XX

4. Control methods and allowable field adjustments are sufficiently prescribed in the design

Final underfloor static pressure requirements should be determined by the balancing contractor. These requirements are directly impacted by how well the underfloor plenum has been sealed. Control methods such as underfloor static pressure reset based on zone temperature and controlled by duct dampers and fan VFD control based on duct static pressure should have adjustable setpoints in the control system to allow fine-tuning. Initial setpoints or expected ranges thereof should be provided in the design documents.

Checks:

		DD	CD	S
A.	Control schemes are completely thought out and documented. The basic operation metrics for the system are identified and defined (supply air temperature and humidity, plenum air temperature and humidity at entrance and expected thermal decay from slab heat gain, pressures, etc.).	X	XX	
B.	Requirements are included for all setpoints and operating parameters needed for fine tuning to be adjustable in the control system front end.	X	XX	
C.	The UFAD design does not limit the ability to operate single or partial floors, if this is required for any off-hours, weekend, or partial building use identified in the Owner's Project Requirements.	X	XX	

5. Balancing requirements are complete

The unique balancing requirements for UFAD systems are typically less defined and leave more to the balancing contractor than conventional systems do. The design engineers need to make clear what performance parameters are fixed by design and what parameters are to be determined in the field by the balancing contractor.

Checks:

		DD	CD	S
A.	Requirements are included for the balancer to make a rough estimation of fan capacity and underfloor air leakage as soon as the raised panels are installed on the first floor (before carpet is down). This provides information as to whether further leak testing is warranted before panels are laid on additional floors.	XX		X
B.	Requirements are included for the balancer to verify construction-quality leakage prior to carpet being laid and total system leakage fraction after carpet is laid. See Issue 6 Performance specifications and functional testing requirements for details.	X	XX	X
C.	Requirements are included for the balancer to determine the lowest underfloor static pressure that can maintain design cfm at the furthest diffusers and set the setpoint at that value (unless reset). Diversity assumptions are included in the requirement, as appropriate.	X	XX	X
D.	Requirements are included for the balancer to adjust the minimum flow setting on each floor diffuser to as low as it can go (ideally zero flow). This allows occupants who need to, to close off their diffuser.	X	XX	

6. Performance and performance testing requirements are adequate

UFAD performance testing requirements are frequently inadequate or missing.

Checks:

		DD	CC	S
A.	Specific requirements that appear in the Owner's Project Requirements and Basis of Design are clearly stated in the project specifications. For example: • Construction-quality leakage (leakage from everything but the actual raised floor plate) is less than 8% of total design flow at 0.05 in. WC pressure. • Floor plate leakage alone with carpet installed and diffusers and data / electrical boxes sealed is equal to or less than the floor panel manufacturer's certified leakage rate. If no certified leakage rate exists, the leakage is less than 15% of design flow at 0.05 in. WC pressure. The floor plate leakage is determined by subtracting the construction-quality leakage from the total system leakage. • The above two criteria result in a total system leakage, which shall be tested after carpet is laid with diffusers sealed and shall be less than the sum of the construction leakage and floor plate leakage criteria. This total system criteria is only valid in conjunction with a passing construction-quality leakage test.	XX		

		DD	**CC**	**S**
B.	Requirements are included for conducting a construction-quality leakage test on the entire first floor finished or at minimum the first 10,000 to 20,000 sq ft of floor panels set, including perimeter and interior spaces. Construction-quality leakage tests are required on one floor for a three story building and 25% of the floors or a minimum of two floors for higher structures. The test specification states that during this test, all floor panels are sealed to walls and columns they butt to and all panel joints, penetrations and diffusers are taped off, thus measuring leakage from everything but the actual raised floor plate. An acceptance criteria of leakage less than 8% of design flow or 0.05 cfm/sf at 0.05 in. WC pressure is stated. The requirements state that whatever special construction or quality assurance processes are required to meet this acceptance criteria shall be used on the rest of the floors. If the first floor fails the first test, it should be sealed until it passes, and another floor will be added to the required number of floors to test and the next floor finished shall be similarly leak tested. If the second floor tested fails its first test, all other floors shall be similarly leak tested.	XX		
C.	Requirements are included for performance of a total system leakage test on each floor, after carpet is laid with all penetrations through the floor plate, and the diffusers and floor boxes sealed. An acceptance criteria of total leakage is less than or equal to the sum of the construction leakage criteria and the floor leakage criteria. Floor leakage is the leakage just through the floor plate itself (with penetrations and diffusers sealed). Floor leakage is not measured in the field, but can be calculated by subtracting the construction leakage from the total leakage. The performance criteria for the floor leakage is the manufacturer's certified leakage rate with carpet panels installed. If no certified values are available, the floor leakage rate can be assumed to be 15% of design flow at 0.05" WC. This test is not valid except in conjunction with a passing construction-quality leakage test. It is not acceptable to perform the total leakage test prior to carpet installation, by using the panel manufacturer's panel w/o carpet leakage rates, unless the construction-quality test was successful. Floors that do not pass shall be sealed until they do pass.	XX		
D.	Requirements are included for proper dehumidification of supply air during varying fractions of outside air.	XX		

		DD	**CC**	**S**
E.	Air handler sequences of operation for ventilation, temperature and pressure control are appropriate and clearly specified. Requirements are included for conducting tests on duct take-off dampers and underfloor damper controls.	XX		
F.	Requirements are included for testing of each perimeter system terminal device: operating it in all of its sequences of operation, including any ties to occupancy and lighting controls.	XX		
G.	Requirements are included for measuring supply air temperature at 15% to 20% of the floor diffusers to ensure there aren't zones with dramatically different supply air temperatures. The test specification states that this test will be performed in warm and cold outdoor weather, that horizontal slab and multiple story slab effects will be analyzed, and will result in recommendations for control adjustments.	XX		
H.	Requirements are included for testing that adjacent zones do not have the potential to compete or adversely cycle.	XX		
I.	Requirements are included for measurement and logging of: • space temperature and humidity at a point 4 ft from the floor in one location per 4,000 sq ft, • supply air temperature, • duct static pressure, • plenum static pressure, • fans speed and • outside air temperature. The requirements include graphing of the measured data and reporting on proper space temperature and RH control and sequences of operation.	XX		
J.	Requirements are included for conducting stratification tests in a few representative locations (at least one location per floor, away from the perimeter and with blinds closed) during summer and winter, using at least seven accurate data loggers vertically set at 6 inches and 3, 5, 6, 7; 9 feet from the floor and one near the ceiling and calibrated to each other. An acceptance criteria of a head-to-foot temperature gradient of between 3°F and 5°F is stated. Should any of the spaces fail, the contractor shall utilize the fine tuning allowance provided to them to try and meet the criteria.	XX		

		DD	CC	S
K.	The specification requires the contractor to perform a set number of hours (e.g., 24 hrs) of fine tuning of duct and under floor pressure set points, supply air temperature set points and reset schedules and perimeter and interior zone space temperature set points after the building has been occupied for 30 days, to account for slab heat gain effects and to optimize stratification. This allowance is in addition to the required stratification tests.	X	XX	

7. Good UFAD design practice is being followed

UFAD is a new technology with considerable ongoing research and evaluation of actual applications. Designers may be using outdated and inappropriate design guidelines.

Checks:

		DD	CD	S
A.	The delivered air to the space via the UFAD diffusers and plate leakage is designed to be 0.3 to 0.6 cfm/sq ft to optimize stratification, energy savings and comfort.	XX		
B.	The supply air capacity is not over-designed. The designed total supply air flow capacity exceeds the sum of the diffusers by an amount to account for construction leakage of no more than 8% of design flow, plus floor plate leakage of no more than a few percent above the floor panel manufacturer’s certified leakage rate with carpet. If no certified values are available, use 15% of design flow. A final 5% to 10% safety factor could also be applied.	XX		
C.	Interior zones are controlled by a thermostat that resets the underfloor pressure so it acts somewhat like a VAV system. (Otherwise, the UFAD system may not achieve energy savings compared to an overhead VAV system and comfort will be compromised.)	XX		
D.	There are no enclosed offices on the same thermostat as open office areas.	XX		
E.	There are return air paths from all enclosed rooms.		XX	
F.	Return air intakes are located above the comfort zone (at least 7 ft from the floor) in order to facilitate stratification.	XX		
G.	When possible, precise floor diffuser locations are not located until the Owner’s furniture layout is known and diffusers are located as far from occupants as possible without being under air-blocking furniture (cabinets, etc.).	XX	XX	XX

		DD	CD	S
H.	Any enclosed perimeter offices will be able to be controlled effectively, which might require duct coils under the floor to additionally heat or cool the air going to the these zones. (Note that UFAD is generally not recommended for enclosed perimeter offices because it is difficult to satisfy these zones and interior zones with the same underfloor air temperature.)	XX		
I.	There are no thermostats in exterior walls or interior walls that extend below the raised floor, unless unavoidable.	XX		
J.	Common underfloor areas served by different air handlers are controlled by one common static pressure sensor or by the average signal from multiple sensors.	XX		XX
K.	The reference sensor to control the underfloor static pressure is located in an area open to the open space and not in an interstitial space or above ceiling tile.	XX		
L.	Static pressure sensors under floors are located away from corners, supply dampers, or near tall pipe runs, cable trays or other obstructions that may cause air moving over them to venturi, resulting incorrect sensor readings.	XX		
M.	Requirements clearly state that static pressure sensors in ducts and underfloor areas have their mid-range near the expected operating pressure.	XX		XX
N.	The humidity control strategy is well designed and specified. In all but very dry climates, reducing the humidity of supply stream should not be limited to the cooling coil providing a >60F discharge temperature. The strategy could include conditioning the return air, outside air and/or supply air.	XX		
O.	Diffusers are not located in higher pressure air highways or ducts (to prevent noise and draft problems).	XX	XX	
P.	Air highways below sensitive areas are insulated for sound.	XX	XX	
Q.	Any underfloor concrete slabs in cold climates exposed over parking or other outside areas and the perimeters of slabs on grade are well insulated, to prevent the underfloor side of the slab from reaching the dew point and for the underfloor temperature to be too low to maintain comfort.	XX		
R.	The air velocity entering the underfloor plenum is less than or equal to 1,500 fpm. High velocities increase unwanted air flow patterns.	XX		

		DD	CD	S
S.	All floor diffusers are within 70 feet of a direct supply air shaft outlet or within 50 feet of the end of an uninsulated air highway or within 60 feet of a slab insulated air highway. Air highways are generally discouraged. Diffusers that are too far away can result in up to a 10F underfloor air temperature rise, due to return air heat from the floor below being transmitted into the slab and into the underfloor air above the slab.	XX	XX	
T.	The designer’s assumptions to account for the slab’s thermal capacity in the load calculations are reasonable. (About 35% of the total room cooling load will be transferred to the underfloor supply plenum for an uninsulated slab and 65% accounted for in the return air. R-10 insulated slabs will have about 10% less transferred to the supply plenum.)	XX		
U.	The designer considered using vertical supply air shafts near the perimeter to provide the coolest air to the perimeter zones that need it more, in warm climates.	XX		
V.	There are never more than two floors served with a single air handler, in multiple story buildings when the return air is exposed to the underside of the slab floor. Otherwise, slabs on upper floors will be warmer than lower floors. Putting higher stories on separate air handlers allows different supply air temperatures. If more than two floors are served by the same air handler, underfloor static pressure reset based on zone temperature is a must.	XX		
W.	The underside of slabs in the upper floors of buildings over seven stories are insulated, if necessary.	XX		
X.	The designer’s assumptions for establishing the design supply air temperature are reasonable (taking into account slab effects).	XX		
Y.	There is at least one underfloor static pressure sensor per 10,000 sf or a minimum of three per floor and the control is to the lowest sensor reading.		XX	
Z.	The supply air temperature delivered to the underfloor is reset based on return air temperature or some other parameter to offer seasonal flexibility and improved comfort and control.	XX		
AA.	The underfloor static pressure is reset based on zone temperature to increase control adaptability and improve comfort, especially when a single air handler serves more than two floors.	XX		

		DD	CD	S
BB.	The supply fan duct static pressure set point should be reset to maintain at least one floor damper fully open (to save energy).	XX		
CC.	Any underfloor variable air volume units (serving perimeters or conference rooms) should be parallel type (not series). Ideally they should include a grill, duct and damper control to draw air from the zone as the first stage of heating and from the underfloor plenum (primary air) as the first stage of cooling.	XX		

8. Facility staff and occupant education and training requirements are included

UFAD systems warrant special operator training and occupant orientation requirements, since they are new and not well understood.

Checks:

		DD	CD	S
A.	Requirements are included for training that covers UFAD system theory and operating principles.	XX		
B.	Requirements are included for training that covers how to adjust the duct, plenum and underfloor pressure and temperature control setpoints, and the impacts of those changes.	XX		
C.	Requirements are included for occupant training that covers how to interact with the UFAD and associated controls.	XX		

9. Underfloor cleanliness requirements are clear

Even if they are initially clean, underfloor areas will likely get dirty from construction processes such as electrical penetrations, damper installation, above floor sheet rock work and other usual activities. What constitutes “clean” and when it will finally be declared “clean” should be explained in the design documents.

Check:

		DD	CD	S
A.	The specification includes a stated expectation of cleanliness or specific methods and frequency of inspection.	XX		

10. Basis of design is adequately documented and available to the construction team

UFAD is relatively new. For many general contractors and subs this could be their first experience with a project and system of this type. Providing a clear, straightforward explanation of the design and an expectation of results will assist contractors in understanding what is being asked of them and may work to prevent problems before they occur.

Check:

		DD	CD	S
A.	A description of the basis of design is included with the specifications or transmitted in some other way to the construction team.	XX		

Resources

Bauman, F.S. (2003) "Underfloor Air Distribution (UFAD) Design Guide," American Society of Heating Refrigerating and Air-Conditioning Engineers.

Bauman, F.S., Webster, T., and Jin, H. (2006) "Design Guidelines for Underfloor Plenums," *HPAC Engineering*. June 2006.

Beaty, D.L. (2004) "Specifying Underfloor Plenums," *HPAC Engineering*. November 2004.

Center for the Built Environment. (2006) "Underfloor Air Technology," CBE website, www.cbe.berkeley.edu/underfloorair. Accessed Dec 2006.

Tate Floors Design and Installation Manuals website. (2006) http://www.tateaccessfloors.com/. Accessed Dec 2006.

Under Floor Air Distribution website. (2006) http://www.ufad.net/ufadncembt.htm. Accessed Dec 2006.

U.S. General Services Administration. (2005) *PBS Guidelines for Raised Floor Systems*.

Webster, T. and Bauman, F.S. (2006) "Design Guidelines for Stratification in UFAD Systems," *HPAC Engineering*. June 2006.

12. Moisture Issues – Envelope and HVAC Related

Moisture control in buildings has been given more attention as the catastrophic and life-threatening problems that can be caused by poor moisture control have become more common. Only recently has the very critical role the HVAC system plays in moisture control been understood. Holistic moisture control design is challenging to implement because it crosses discipline lines, requiring coordination between the architectural and HVAC disciplines. Many teams are unaware of the negative implications of their designs, particularly in hot, humid climates where moisture from outside can easily be drawn into building cavities and directly into the space, resulting in microbial contamination. There are a number of items to look for in designs that can minimize the potential for these problems to exist.

Below are four issues frequently encountered in design reviews:

1. General and architectural factors affecting moisture are clearly covered in specifications and drawings
2. Envelope components are appropriate and will not contribute to moisture intrusion or mold growth
3. HVAC components and control will not contribute to negative pressure in rooms or interstitial spaces
4. HVAC components and control will not directly contribute to high moisture levels in the space

1. General and architectural factors affecting moisture are clearly covered in specifications and drawings

Checks:

		DD	CD	S
A.	The owner requirements and basis of design clearly state an intention to ensure envelope moisture integrity.	XX		
B.	In hot and humid climates, wall coverings on the inside of exterior walls do not serve as vapor barriers, as vinyl does, which will trap moisture and lead to mold growth. Required minimum permeability should be specified as greater than 1 perm. Standard latex or oil-based paints are greater than 1 perm. In general, wall component permeability increases from interior to exterior.	XX	XX	
C.	The owner requirements and basis of design clearly state an intention to control the movement of moisture through the walls, floors and ceilings of interior spaces with special moisture requirements.	X		

2. Envelope components are appropriate and will not contribute to moisture intrusion or mold growth

Checks:

		DD	CD	S
A.	Air and water leakage requirements of exterior envelope components are adequately included in the specifications, and are appropriate for the building and climate.	XX		
B.	In hot and humid climates, wall assembly vapor transmission and dew point calculations are provided for critical applications.	XX		
C.	Wall assemblies are clearly shown in the drawings and details. Materials are adequately identified and specified in specific terms. For example, the terms “sheetrock”, “poly vapor barrier”, and “sealant” are too general unless a description key is provided indicating what type of sealant, etc.	X	XX	XX
D.	Weep holes exist through masonry exteriors to provide a means for moisture to escape and not be trapped within exterior wall cavities.	X	XX	
E.	Weep holes are provided at all through-wall flashings and ledger beams where a means for vertical moisture flow is provided.	X	XX	
F.	Vertical through wall flashings and associated weep holes are exposed to daylight above grade.	X	XX	
G.	Masonry wall cavities between rain screen masonry and interior walls have at least 2 inches clear space, per Masonry Institute recommendations.	X	XX	
H.	The interior wall surface of all exterior masonry cavities are protected with a rain barrier surface that continually directs rain water to the outside.	X	XX	
I.	Vapor retarders are located properly for the wall assembly and climate. In hot and humid climates, the vapor barrier/retarder is generally located on the outside of the insulation. In cold and dry climates, the vapor barrier/retarder is located on the inside of the insulation.	X	XX	
J.	Any critical junctures where water will flow and accumulate are detailed and will not result in water leakage. This is especially important around windows and doors, corners, parapets, sloped glazing, balconies, etc.	X	XX	

		DD	CD	S
K.	No horizontal joints in façade components rely solely on caulk sealant for waterproofing. If this must be the case, drainage planes, paths and weeps are provided.	X	XX	XX
L.	Flashing details are provided and flashing is properly designed.	X	XX	
M.	All façade “sills” are downwardly sloped outwards.	X	XX	
N.	Precast concrete and other structurally connected elements show proper sealing details.	X	XX	
O.	Gypsum sheathing used on the exterior of walls, underneath the cladding, is water- and mildew-resistant.	X	XX	XX
P.	The envelope of any interior spaces that are kept at higher humidity than adjacent spaces are constructed to prevent condensation.			

3. HVAC design, components and control will not contribute to negative pressure in rooms or interstitial spaces

Checks:

		DD	CD	S
A.	In humid climates, a conservation of mass calculation on moisture has been conducted by the designer. If this has not been done, the reviewer should conduct one. This calculation indicates the design is putting less moisture into the building than is being removed.	XX		
B.	Air pressure relationships between outdoors and indoors across the entire envelope are clearly specified.	XX	XX	
C.	In humid climates, drawings show sufficient transfer paths for supply air to move to exhaust air inlets served by exhaust fans, without making interior spaces, particularly rooms on outside walls, negative. For example, if a perimeter room becomes negatively pressured because the exhaust air inlets are “starved”, moisture-laden air may be drawn in from outside through interstitial cavities.	XX	XX	
D.	Exhaust air flow is minimized to reduce the amount of infiltration that can cause moisture problems and the amount of make-up air that can lead to excessive dehumidification energy use. For example, in hotels, intermittent on-demand bathroom exhaust fans may be an alternative to continuous exhaust in designs that are not relying on corridor fresh air pressurization for fresh air to the rooms.	X	XX	

		DD	CD	S
E.	Total exhaust air quantity or capacity is at least 10% less than the total makeup air quantity or capacity to allow the building to be positively pressurized.	X	XX	
F.	The building static pressure control scheme is designed to keep the building positively pressurized.	X	XX	
G.	In hot and humid climates, fan coil units in walls or ceiling spaces have ducted returns to prevent negatively pressurized interstitial cavities that may draw in moist outside air.	X	XX	
H.	In hot and humid climates, rooms served by fan coil units on exterior walls receive outside air from a common corridor duct, rather than having direct outdoor air intakes through the fan coil unit.	XX	XX	XX
I.	In hot and humid climates, there are no filters on return air grills leading to ceiling plenums. Dirty filters cause negative pressure in the ceiling, which can draw outside air into walls and ceiling cavities.	X	XX	XX

4. HVAC components and control will not directly contribute to high moisture levels in the space

Checks:

		DD	CD	S
A.	For climates or applications where moisture control is important, this control is specifically addressed in the basis of design.	XX		
B.	Operating sequences for all air handling systems that introduce outside air ensure adequate control of moisture.	XX	XX	XX
C.	In hot and humid climates, makeup air units incorporate discharge air temperature control to maintain sufficient control of moisture levels.	XX	XX	XX
D.	In hot and humid climates, insulation and vapor retarders are installed on all surfaces that could be below dew point and are in contact with unconditioned outdoor air.		XX	XX
E.	The strategies for summer chilled water temperature and discharge air temperature resets will not compromise dehumidification capacity. For example, if resets are too high, dehumidification will be reduced.	X	XX	
F.	Reheat capacity is provided, as needed, to reheat cold dehumidified air for temperature control.	X	XX	XX

		DD	CD	S
G.	Chilled water piping insulation is non-hygroscopic. It uses flexible unicellular, cellular glass or polyolefin.	X	XX	XX
H.	Continuous vapor retarder jackets are shown on chilled water piping. Quality control and assurance requirements are identified in the insulation specifications.	X	XX	XX
I.	Air conditioning equipment is specified with internal insulation, including a vapor barrier in cold air compartments.	X	XX	XX
J.	Pipe and duct support systems are provided with rigid inserts and allow the vapor retarder jacket to be continuous through the support.	X	XX	XX
K.	Floor and wall penetrations for fire-rated insulated assemblies are provided with appropriate UL listed methods that are appropriate for the insulation system and allow a continuous vapor retarder jacket.	X	XX	XX
L.	Chilled water systems are specified to not be energized at startup until all pipe insulation is complete and building is enclosed so that condensation will not occur on the insulation jacket.	X	XX	
M.	Specifications for temporary cooling controls during construction avoid over-cooling of spaces and minimize vapor migration into building materials and condensation on cooled surfaces.	X	XX	
N.	Thermostatic controls prevent occupants from over-cooling spaces, minimizing vapor migration into building materials and condensation on cooled surfaces.	X	XX	
O.	Air velocity at cooling coils does not exceed 500 fpm to prevent condensate carryover.		XX	
P.	For low temperature air distribution systems (where the supply air temperature is below typical ambient dew point), the supply air system is fully insulated and wrapped in a continuous vapor barrier from the AHU to the diffuser, including terminal unit coil connections.	X	XX	XX
Q.	For low temperature air distribution systems (where the supply air temperature is below typical ambient dew point), appropriate high induction supply air diffusers are specified.	X	XX	XX

Resources

ASHRAE. (2005) “Thermal and Moisture Control in Insulated Assemblies -Fundamentals,” *ASHRAE Handbook of Fundamentals*.

ASHRAE. (2005) “Thermal and Moisture Control in Insulated Assemblies -Applications,” *ASHRAE Handbook of Fundamentals*.

ASHRAE. (2007) “Design Criteria for Moisture Control in Buildings,” *ASHRAE Standard 160*.

Harriman, L., Bundrette, G., and Kittler., R. (2001) “Humidity Control Design Guide for Commercial and Industrial Buildings,” American Society of Heating Refrigerating and Air Conditioning Engineers.

13. Staging and Low-Flow Operation Issues

Chillers, boilers and direct expansion (DX) cooling equipment must be designed to respond to changes in load. Load changes in the building are typically continuous and gradual, but the equipment can only respond in steps. Careful planning is required to ensure that the capacity staging process is as smooth as possible and doesn't exhibit large abrupt changes in chilled water, heating water or supply air temperatures resulting in compromises in energy efficiency and comfort or short cycling that reduces equipment life. Many buildings require very low load operation during off-hours or off-season, especially during initial interior build-out. Too frequently, central plant equipment is not designed properly to operate at these low loads, resulting in systems that short cycle and have reduced equipment lives.

Below are three categories of staging and low-flow issues, each with a number of checks.

1. Chiller, boiler or DX staging plan is clear and will work as intended.
2. Chillers and boilers can operate at low loads without short cycling.
3. Varying water flow through the chillers or boilers will not result in chiller surge, boiler high-limit cut out and equipment short-cycling.

1. Chiller, boiler or DX staging plan is clear and will work as intended

Checks:

		DD	**CD**	**S**
A.	Parameters that equipment staging is based upon are as direct as possible (e.g., for an internal load dominated building, outside air temperature may not be a good indicator of cooling demand).	X	XX	XX
B.	Staging parameters (and reset schedules) utilizing valve position or cooling or heating demand is based on two or more devices. When relying on only one device (e.g., position of the single most open valve), a bad installation or sensor can inappropriately drive the entire control loop.	X	XX	XX
C.	Conditions for staging up and down, deadband settings and/or delays are clearly specified and provided at each stage of primary plant equipment to prevent pre-mature staging and short cycling. A method is explicitly given for managing the transient spiking up and down of flows and resultant changes in chilled water supply temperature during chiller staging to prevent short cycling.	X	XX	XX
D.	Control parameters (e.g., deadband intervals, delays and ramp times) are identified properly to avoid system interactions that can lead to instability. For example: Chiller staging affects chilled water supply temperature, which affects cooling coil valve position.	X	XX	XX

		DD	CD	S
E.	The number of DX compressor stages (which is a function of the number of compressors and the way they are circuited) for packaged air handlers will provide small enough step changes in cooling capacity to yield an acceptable fluctuation in discharge air temperature, especially for VAV systems during lower airflow rates.	X	XX	XX
F.	DX equipment is provided with hot-gas re-injection (bypass) on first cooling stage, if low load potential will cause too much cycling of lead stage compressor.	X	XX	XX
G.	DX equipment has been specified with head pressure control of condenser fans for operation at low ambient temperatures or low loads.	X	XX	XX
H.	Parallel operated chillers and boilers can send and receive required staging parameters to allow the proposed staging sequences to function correctly (e.g., chiller kW, amps mapped back to building automation system or flow and temperature calculated load confirmation).	X	XX	XX
I.	In primary/secondary systems, the chilled water system sequence of operations should prevent the secondary loop flow rate from exceeding the primary loop flow rate. If the secondary flow exceeds the primary flow, the secondary loop will cycle higher in temperature and the overflow condition will increase, causing loss of space temperature control.	X	XX	XX
J.	Boiler piping and startup sequence avoid unacceptable thermal shock to the boilers.	X	XX	XX
K.	Process loads are described in the basis of design and are adequately addressed in the design.	X	XX	

2. Chillers and boilers cannot operate at low enough loads without short cycling

Checks:

		DD	CD	S
A.	The continuous turn-down ratio or size of the smallest chiller or boiler is in line with the lowest expected heating and cooling load that will occur frequently or be experienced for any significant length of time (assessed by asking the designer for the results of their calculations, and taking into account off-season and off-hours operation and the less than fully occupied condition that may exist for years). Some cycling is expected at the lowest loads, but cycling should be limited to manufacturer recommendations.	XX	XX	
B.	The designer has considered installing a small local chiller to handle very low load requirements, rather than hot gas bypass on the main chiller (trading off the higher first costs against long-term energy savings).	XX	XX	
C.	Sequences clearly describe how short cycling will be avoided at low loads. Minimum flow rates are clearly described in the sequences. Installation of equipment and piping are consistent with the sequence.	X	XX	XX

3. Varying water flow through the chillers and boilers will not result in chiller surge, boiler high limit cut out and equipment short-cycling

Checks:

		DD	CD	S
A.	Minimum flow rates are clearly described in the sequences. Installation of equipment and piping are consistent with the sequence.	X	XX	XX
B.	Boiler equipment specifications indicate the limitation of flow variation and ability to turn down without short cycling.	X	XX	XX
C.	Boiler circulation (blend) pumps have been provided to maintain constant flow through the boiler, while the primary/secondary distribution system is variable flow.	X	XX	XX

Resources

Avery, Gil. (1993) "Design and Commissioning Variable Flow Hydronic Systems," *ASHRAE Journal*. July 2003.

McQuay. (2002) "Chiller Plant Design," *Application Manual. AG 31-003-1*. McQuay website, http://www.mcquay.com/McQuay/Literature/Literature. Accessed Dec 2006.

Taylor, S. (2002) "Balancing Variable Flow Hydronic Systems," *ASHRAE Journal*. October 2002.

Trane Engineer's Newsletter. (2002) "Variable Primary-Flow Systems Revisited." Trane website, http://www.trane.com/commercial/library/vol31_4/index.asp. Accessed Dec 2006.

14. Outdoor Air Control Issues

Outdoor air control is a critical issue in every design, as it directly affects occupants' health and comfort. The control of outdoor air also has a dramatic impact on energy costs. Subsequently, making sure the designer's intentions for outdoor air control are well founded and clearly communicated as important elements of every design review.

Below are five categories of outdoor air issues, each with a number of checks.

1. Ventilation air quantities and calculations for each air handler are provided and correspond with the latest edition of the ASHRAE Standard 62 ventilation standard.
2. Basis of design is clear, and effective control logic and setup procedures for each air handling unit's minimum outside air control are clearly specified.
3. Demand controlled ventilation strategy is clearly specified in the construction documents and documented in the basis of design.
4. Economizer sequence of operation is clear and adequately describes proper operation.
5. Outdoor air intakes are properly located.

1. Ventilation air quantities and calculations for each air handler are provided and correspond with the latest edition of the ASHRAE Standard 62 ventilation standard

Checks:

		DD	CD	S
A.	The minimum and maximum outdoor air rates for each air handler are listed on the equipment schedules.	X	XX	
B.	The number of occupants that were assumed in the minimum ventilation rates and the source for these assumptions are described in the basis of design. These numbers should match the Owner's Project Requirements and be reasonable (e.g., not based on default occupancy tables, if actual expected occupancy is different, unless required by code).	XX	XX	
C.	The procedure and assumptions used to comply with ASHRAE Standard 62 are included in the basis of design (Ventilation Rate or IAQ Procedure, number of occupants by air handler zone and floor area, recirculation, partial occupancy; ventilation efficiency assumptions and results, etc.). The assumptions and objectives match the Owner's Project Requirements.	XX	XX	

2. Basis of design is clear, and effective control logic and setup procedures for each air handling unit's minimum outside air control are clearly specified.

Checks:

		DD	CD	S
A.	The basis of design of how the minimum ventilation rate is to be controlled is clear, sound and reasonable. .	XX		
B.	When not utilizing CO_2 demand controlled ventilation or a direct method for measuring minimum outdoor air flow, the minimum damper position varies as a function of fan speed so a closer to absolute ventilation flow rate is maintained and energy is conserved.	X	XX	
C.	If the specifications call for a single fixed minimum percent outside air, then the plans and specifications shall also indicate that the minimum damper position be determined at the expected minimum supply air flow rate (required in ASHRAE Guideline 62-2004). However, during warmer weather this strategy of a fixed minimum may result in excess outside air and the accompanying energy waste.	X	XX	
D.	Setup and documentation procedures, parameters and criteria for minimum outside air setup are clearly coordinated and specified in the balancing and BAS specifications.	X	XX	
E.	If a speed or flow offset is used to control the speed of the return fan from the speed of the supply fan, that offset should vary as supply fan speed increases, rather than being a fixed value (which would be inaccurate at lower speed).	X	XX	
F.	Minimum outdoor air control is not based on mixed air plenum pressure, unless the designer has considered the inherent complexities and alternate methods.	X	XX	
G.	On large built-up air handlers, minimum outdoor air flow measuring stations are utilized. If they are not, a reasonable explanation is provided in the basis of design.	X	XX	XX
H.	Flow measuring stations, if used, are properly located to sense a fully developed air flow profile, and have adequate filtration or protection from particulate loading. Access doors have been provided for testing and verification of air flows.	X	XX	XX

3. Demand controlled ventilation strategy is clearly specified in the construction documents and documented in the basis of design

Checks:

		DD	CD	S
A.	In demand controlled ventilation schemes, the design minimum ventilation rate is no more than the Area Outdoor Air Rate in ASHRAE Standard 62 Table 6-1 (subject to exhaust issues below and acceptable CO_2 levels). This conserves energy.	X	XX	
B.	In demand controlled ventilation schemes, the minimum ventilation rate is larger than the sum of the background and transient exhaust fan flow rates, in order to maintain positive building pressure.	X	XX	
C.	In demand controlled ventilation schemes, CO_2 sensors in the return air stream of an air handler only average the zones they serve. Therefore, CO_2 sensors are not normally used in the return air stream of air handlers that serve multiple zones, when the sensors will be used control to a minimum ventilation rate near the ASHRAE Area Outdoor Air Rate or maximum CO_2 level. Using CO_2 sensors in return air plenums serving multiple zones may be acceptable, if the CO_2 control point was very conservative (e.g., control to 700 ppm rather than 1000), but this wastes energy and is not advised.	XX	XX	XX
D.	In demand controlled ventilation schemes, CO_2 sensors comply in location and quantity with ASHRAE and other applicable codes, such as California’s Title 24.	X	XX	XX
E.	In demand controlled ventilation schemes, CO_2 sensors are “self-calibrating” or automatically re-reference against background levels, not requiring manual recalibration for 5 years for more.	X	XX	XX
F.	In demand controlled ventilation schemes, the rationale for needing a dedicated outdoor air CO_2 sensor to continuously measure outside CO_2 vs. inside CO_2 is apparent, compared to using data from one-time spot measurements of outdoor CO_2, which may be adequate and cost less to install and maintain.	X	XX	

		DD	CD	S
G.	In demand controlled ventilation schemes, the subsequent equipment actions when the CO_2 set point has been reached is clearly specified (e.g. terminal goes full open; if still not satisfied, outdoor air dampers modulate or go full open, etc.). Verify that if outdoor air dampers modulate to full open position, coil freeze protection and cooling/heating load capacity can adequately condition up to the maximum outdoor air quantity possible.	X	XX	
H.	In demand controlled ventilation schemes, CO_2 sensors are shown to be mounted where they will not be in close proximity to occupants or near a supply air diffuser.	X	XX	

4. Economizer sequence of operation is clear and adequately describes proper operation

Checks:

		DD	CD	S
A.	The economizer sequence of operation clearly specifies when the economizer is locked out (fixed outdoor air temperature, outdoor air vs. return air—dry bulb difference, enthalpy difference with one or both measured, etc.). Conditions for lockout and unlock are clearly specified with adequate deadband.	X	XX	
B.	The mixed air low limit control is clearly specified and is not higher than it needs to be, recognizing that in cold climates, with high minimum outdoor air fractions (and preheat coils) a mixed air low limit may not be appropriate. Higher mixed air low limit values reduce economizer hours.	X	XX	
C.	The economizer can function in full economizer mode during mechanical cooling (integrated economizer).	XX	XX	
D.	Outdoor and return air sensors are properly selected, properly located to provide accurate and repeatable measurements for controlling economizer operation. Averaging sensors cover the entire duct or coil face areas. Also see Review Area #2 Sensors.	X	XX	XX

5. Outdoor air intakes are properly located

Checks:

		DD	CD	S
A.	Outdoor air intakes are not near other building exhaust or relief outlets. The design meets requirements in ASHRAE Standard 62, Outdoor Air Intakes section, including Appendix F.	XX	XX	XX
B.	Outdoor air intakes are not near sources of contaminants (loading docks, street intersections with stoplights, parking areas where cars can idle, trash bins, moisture sources, including cooling towers). Design meets requirements in ASHRAE Standard 62, Outdoor Air Intakes section, including Appendix F.	XX	XX	XX
C.	Outdoor air intakes are arranged where they will not be clogged with leaves or litter.	XX	XX	
D.	Outdoor air intake ducts do not have duct liner (microbial concerns).	X	XX	
E.	Outdoor air intakes are sized with low enough pressure drop to avoid entrainment of rain water, accounting for how protective the intake configuration is.	X	XX	XX
F.	Low leakage outside air dampers are used, which are accessible for routine inspection and maintenance.	X	XX	XX

Resources

ASHRAE. (2003) *Selecting Outdoor, Return, and Relief, Dampers for Air-side Economizer Systems*. ASHRAE Guideline 16P -2003.

ASHRAE. (2004) *Ventilation for Acceptable Indoor Air Quality*. ASHRAE Guideline 62.1-2004.

California Energy Commission. (2003) "Advanced Variable Air Volume System Design Guide." CEC website, http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF. Accessed Dec 2006.

Jeannette, E. and Phillips, T. (2006) *Designing and Testing Demand Controlled Ventilation Strategies*. Paper presented at the National Conference on Building Commissioning, San Francisco.

National Building Information Controls Program. (2006) "Return Fan Control Methods Application Guideline." NBICP website, http://www.buildingcontrols.org. Accessed Dec 2006.

15. Duct Design Issues

Although duct design is a common and basic engineering activity, much of the routing and final design of the duct system is left to the contractor. Due to competition for space by multiple trades and lack of coordination of space allocation during the design phase, many energy saving features and opportunities may be forfeited if not clearly specified and shown in the design documents. Careful review and attention to details in the contract documents will ensure these issues are brought to the attention of the designers when they can still be easily incorporated into the project.

Below are three areas that should be evaluated during design reviews.

1. Duct requirements and definitions are clear and take advantage of energy savings potential
2. Duct lengths, fittings, turning vanes and transition requirements are clear and take advantage of energy savings potential
3. Drawings are more than schematic in nature and include all fittings necessary for installation

1. Duct requirements and definitions are clear and take advantage of energy savings potential

Checks:

		DD	**CD**	**S**
A.	The duct leakage class is clearly specified.	XX	XX	XX
B.	Ductwork is specified to be fabricated and installed per current industry standards (i.e. SMACNA HVAC Duct Construction Standards).	XX	XX	XX
C.	The most restrictive branch from the fan to the last air terminal unit is identified, and there is no reasonable way to significantly reduce its pressure drop. Note that reducing the pressure drop in anything but the most restrictive branch will not directly reduce the total fan static pressure required.	X	XX	
D.	Ductwork sealing requirements and criteria are clearly specified, citing applicable duct locations, pressure class, SMACNA seal class. SMACNA requires the information to be placed on the drawings as well as in the specifications.	XX	XX	
E.	Pressure testing requirements and acceptance criteria are clearly stated in specifications, citing applicable duct locations, pressure class, percent of duct to be tested, test pressure, leak class and leakage factor (cfm/sf).	XX	XX	
F.	Duct thermal insulation material requirements are clearly stated in specifications and/or drawings.	XX	XX	

		DD	CD	S
G.	Duct acoustical insulation material requirements are clearly stated in specifications and/or drawings.	XX	XX	
H.	A ductwork table, which lists system, portion of duct applicable, duct material, pressure class, SMACNA seal class, percent of duct to be pressure tested, test pressure, leak class, leakage factor (cfm/sf) and insulation type and thickness, is included for larger more complex projects.		XX	
I.	Duct interior insulation material is set back or lined to prevent moisture from humidifiers from collecting in or on insulation. Humidifier manufacturer's recommendations are given.		XX	
J.	Branch duct systems are designed for equal pressure drop, when possible.		XX	
K.	Duct branches with significantly differing static pressure requirements have volume control dampers strategically placed to aid in TAB work.		XX	
L.	Outlets with different static pressure requirements have duct mounted dampers to equalize pressures and avoid noisy outlets.		XX	

2. Duct lengths, fittings, turning vanes and transition requirements are clear and take advantage of energy savings potential

Checks:

		DD	CD	S
A.	Fans discharge into duct sections that remain straight for as long as possible (ideally 10 duct diameters) to reduce fan inefficiencies from system effects.	XX	XX	XX
B.	Ducts are designed to be as straight as possible. Straight ducting will minimize pressure losses and provide for the lowest material costs.	X	XX	
C.	Return air shafts allow air velocities in the 800 – 1200 fpm range through the free area at the end of the shaft nearest the air handler.	XX	XX	
D.	Duct sound traps are used only when absolutely required.	XX	XX	
E.	Duct velocities are generally below 2,000 fpm for ducts in ceiling plenums,1500 fpm for exposed ducts and 3,500 fpm in mechanical rooms and non-noise sensitive shafts.	X	XX	

		DD	CD	S
F.	Duct friction rates are generally less than 0.25” WC per 100 lineal feet nearer the fan, 0.15 to 0.20” WC per 100 lineal feet in the main ducts and 0.08 to 0.12” WC per 100 lineal feet nearer the end of the system. Designs based on rates greater than these should be questioned. Very energy efficient design can lower these values by up to 40%.	X	XX	
G.	All duct size transitions are at least 20 feet apart.	X	XX	
H.	Transitions are positioned to take advantage of standard duct lengths to reduce installation costs (2 feet for spiral round ducts, 12 feet for oval, 5 feet for rectangular).	X	XX	
I.	Spiral duct is utilized rather than rectangular, as space permits. Spiral duct generally is less expensive, utilizes less metal, making it more sustainable, is less prone to leakage, produces less low frequency sound, and requires less thermal and acoustical insulation.	XX	XX	XX
J.	Any rectangular elbows with a radius and with a velocity over 700 fpm has a radius-to-width ratio greater than 1.5, unless a splitter vane is used. The radius is to the centerline of duct. Width is the duct dimension in the direction of the radius. Square elbows with turning vanes are used only where radius elbows will not fit to mitigate sound and pressure loss issues.	X	XX	XX
K.	Turning vanes should be single width (layered), unless they need to be double width for structural reasons. If single width, a 2 inch radius and 1.5 inch spacing without a trailing edge is recommended over a 4.5 inch radius and 3.3 inch spacing (which as a 66% higher pressure drop). If a 4.5 inch radius is used, it should have a trailing edge or a spacing of 2.3 inches. If using double width vanes, a 2 inch radius and 2.2 inch spacing is recommended over a 4.5 inch radius and 3.3 inch spacing (which has a 40% higher pressure drop).	X	XX	XX
L.	Rectangular branch duct take-offs are of “increased area” or “saddle” type (45 degrees on one side) rather than having straight/square taps. No extractors or splitter dampers are used.	X	XX	XX
M.	Conical round branch take-offs are used from medium pressure duct, and straight taps are used from low pressure duct.	X	XX	XX
N.	Elbows are not used to transition duct sizes (e.g., 28x8 entering and 20x8 leaving).	X	XX	
O.	There are no unnecessary 90 degree elbows close to one another (within 2 duct diameters). Two 45 degree fittings can be used instead.	X	XX	

		DD	CD	S
P.	There are no unnecessary duct take-offs close to fittings, other take-offs, transitions or elbows.	X	XX	
Q.	Fans do not discharge into an elbow, unless absolutely necessary.	X	XX	
R.	Fan discharge utilizes a bell-mouth fitting when discharging into a duct larger than the fan outlet.	X	XX	XX
S.	Flex duct does not exceed 7 feet in length and is configured as straight as possible.	X	XX	
T.	Flex duct minimum bend radii is specified to be not less than one duct diameter. Flex duct runs should be limited to low velocity runs of less than 8 feet.	X	XX	
U.	Sheet metal inlets to VAV terminal boxes are specified, rather than flex duct.	X	XX	
V.	Flex duct support is adequate to minimize sagging.	X	XX	XX
W.	Final connections to diffusers are plenum cans of hard duct, not flex connections.	X	XX	XX

3. Drawings are more than schematic in nature and include all fittings necessary for installation

Checks:

		DD	CD	S
A.	sizes, including transitions, are clearly indicated and appropriate for the application. Duct is sized by inside dimensions, accounts for interior insulation thicknesses and pressure losses for air flow, and accounts for exterior insulation thicknesses for space coordination requirements.	X	XX	
B.	work shown on drawings is dimensioned double-line. Single line is not acceptable, except for final diffuser connections.	X	XX	
C.	er and support details and requirements are per SMACNA and details are included in design drawings.	X	XX	XX
D.	ie Design Review checks for Balancing Issues for a list of balancing damper location requirements.	X	XX	
E.	-offs directly to grilles, registers and diffusers are not off of main ducts.	X	XX	
F.	penetrations are clearly detailed with required fire/smoke damper and fire rated caulking requirements included. The penetration protection class is given according to local code criteria.	X	XX	
G.	per actuators are accessible for inspection & service, including fire/smoke dampers.	X	XX	

Resources

ASHRAE. (2005) "Duct Design," *ASHRAE Handbook of Fundamentals*.

California Energy Commission. (2003) "Advanced Variable Air Volume System Design Guide." CEC website, http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF. Accessed Dec 2006.

Energy Design Resources. "Design Briefs: Design Details." Energy Design Resources website, http://www.energydesignresources.com/resource/25/. Accessed Dec 2006.

Energy Design Resources. "Design Briefs: Design Review." Energy Design Resources website, http://www.energydesignresources.com/resource/26/. Accessed Dec 2006.

National Environmental Balancing Bureau. (2005) *Design Phase Commissioning Handbook*.

SMACNA. (1995) *HVAC Duct Construction Standards, Second Edition*.

16. Pump, Piping and Plant Design Issues

Though the configurations of central plant piping and equipment layouts can vary widely, some common types have emerged. However, even with these common designs, misjudgments and omissions related to hydraulic and controls theory are common findings in design reviews. The result, when not caught during design, is increased change orders, lengthy troubleshooting excursions and long delays into occupancy before systems are debugged and operating properly. Persistent control problems and energy waste also accompany these issues.

Below are five areas that when covered during design review can improve the hydronic systems in buildings.

1. General central plant piping design appears correct
2. Condenser / cooling tower loop appears to be designed correctly
3. The variable flow system design is sound
4. Pumps appear to be selected and piped properly
5. Cleaning, flushing and water treatment appears to be specified adequately

1. General central plant piping design appears correct

Checks:

		DD	CD	S
A.	The piping arrangement and design is not in conflict with the sequences of operation. This can be verified by analyzing the flow diagram (or creating one, if needed).	X	XX	
B.	Spatially, chillers and boilers are sufficiently separated to comply with NFPA.	XX	XX	
C.	Boilers and chillers that are in parallel and are without dedicated pumps have automatic isolation valves to prevent unwanted bypass through the equipment when not operating.	X	XX	
D.	Chillers that are located in the basement, and their associated valves, have sufficient pressure ratings to handle the static head of roof-mounted cooling towers, when applicable. Likewise, equipment in campus applications can handle head requirements.	X	XX	
E.	Sufficient isolation valves exist to allow replacing each pump, chiller, boiler or control valve without draining the entire system.	X	XX	
F.	Boiler combustion air requirements appear to meet code requirements and will not cause the boiler room to go negative in pressure.	X	XX	

		DD	CD	S
G.	There are unions on both sides of control valves, unless the valves have flanged fittings for maintenance.	X	XX	
H.	Piping is arranged with as few bends as possible. Long radius elbows are used where possible. See Design Review Area on Energy Efficiency for additional information.	X	XX	
I.	Piping over 4 inches in diameter is shown on the drawings as dimensioned double-line, with sections provided for complicated or tight spaces.	X	XX	

2. Condenser/cooling tower loop appears to be designed correctly

Checks:

		DD	CD	S
A.	Cooling towers have sufficient automatic isolation valves to prevent tower water flow from going below the tower minimum rating when there are fewer chillers than towers running.	X	XX	
B.	Cooling towers in parallel have adequate sump equalization lines with manual isolation valves for maintenance.	X	XX	
C.	Cooling towers are elevated enough above the condenser water pumps to provide needed net positive suction head (NPSH) to prevent pump cavitation. If the bottom of the cooling tower basin is not at least five feet above the pump centerline, or piping has several changes in elevation, ensure that NPSH has been evaluated.	XX	XX	
D.	Freeze protection is adequately addressed for winter process operation.	X	XX	
E.	Adequate cooling tower makeup water is provided, complete with heat tracing and level control, and is interlocked with the water treatment system.	X	XX	
F.	Cooling tower plume will not allow re-entrainment into outside air intakes under normal operating conditions. Air handlers will not cause reverse flow through the cooling tower during low tower fan speed operation.	X	XX	
G.	Multiple cooling towers (cells) are piped for equal pressure drop to each hot basin, or are fitted with flow balancing valves.	X	XX	

		DD	CD	S
H.	Multiple cooling towers (cells) are equipped with automatically controlled isolation valves when required by the sequences of operation.	X	XX	

3. The variable flow system design is sound

Checks:

		DD	CD	S
A.	Variable flow design makes sense for the application. Pump energy savings have been analyzed against resetting chilled water temperature.	X	XX	
B.	In a variable flow primary chilled water system, all chillers within the system are designed for nearly the same evaporator water-side pressure drop. This will increase stability.	X	XX	
C.	In a variable flow primary chilled water system, the bypass line control valve is fast-acting and has a linear position vs. flow curve. To improve speed of response and reliability, this valve is wired directly to its controller, not to another controller or over the network.	X	XX	XX
D.	In variable flow systems, whether primary/secondary or primary only, the system design balances energy savings and lower pump first costs from reduced pressure drop against higher material and labor costs to achieve the lower pressure drop; and the design accounts for cost differences in the required balancing valves and labor. This should result in a system that utilizes conventional pipe and control valve sizing and configurations (not reverse return), does not require any balancing valves (other than one at the takeoff of the first few branches nearest the pump), and does not require auto-flow valves or traditional branch balancing labor. Refer to Taylor, S. (2002, Oct). “Balancing Variable Flow Hydronic Systems.” ASHRAE Journal for more detail on this design.	XX	XX	
E.	In primary/secondary variable flow systems, the bypass line is in the proper location to decouple the primary/secondary loops. This decoupler is sized to handle only the flow of the largest chiller or boiler. The return side of the decoupler is located so mixing can occur before the first takeoff to a chiller or boiler. Verify that sensors are mounted far enough away from the decoupler so they do not read an unmixed water stream.	X	XX	

		DD	CD	S
F.	In variable flow systems, the 2-way branch (coil) valves are sized with a pressure drop equal to or slightly greater than the drop in the rest of the branch.	XX	XX	XX
G.	In variable flow systems, the branch (coil) valves are equal percentage type, rather than linear. The non-linear nature of equal percentage valves (flow vs. percent open), combined with the opposite non-linear nature of coil heat transfer vs. flow, results in a near-linear relationship between valve percent opening to heat transfer, giving more stable control.	X	XX	XX
H.	In variable flow systems, the branch (coil) dynamic valve rating (closing ability against pressure) is at least 1.5 times the design pump head.	X	XX	
I.	In variable flow systems, the branch (coil) valve close off rating is at least 1.5 times the design pump head.	X	XX	

4. Pumps appear to be selected and piped properly

Checks:

		DD	CD	S
A.	A reality check of the pump sizing indicates it does not appear to be oversized. The pump pressure drop from the equipment schedules can be compared to the system pressure drop, which can be estimated from equipment schedules and pipe lengths as follows: • Coils: Control valve pressure drop assumed to be about equal to coil pressure drop • Main piping: Assume a pressure drop of about 1 to 2” WC for each effective foot of pipe length. Assume that the effective pipe length is about 1.25-2 lineal feet for each actual foot of length, to account for fittings. • Runouts to AHUs: Assume a pressure drop of about 2 feet WC for each effective foot of pipe length. Assume that the effective pipe length is about 4 lineal feet for each actual foot of length, to account for fittings.	X	XX	
B.	If there is a chance a constant speed pump will be run at much lower than the design pressure drop, ask the designer to ensure that the pump is non-overloading, so if it runs out its curve, it will not over-amp the motor.	X	XX	XX
C.	Pumping is not toward the expansion tank, which leads to air coming out of solution, noise, and air binding equipment.	X	XX	

		DD	CD	S
D.	A suction diffuser is specified or shown for each pump that has fewer than five to ten pipe-diameters of straight pipe immediately before its suction inlet. Ten diameters is ideal.	X	XX	
E.	Eccentric reducers are specified to be installed in the correct configuration. The top of the reducer should go straight into the suction flange.	X	XX	
F.	Suction piping is generally at least one size larger than the suction flange at the pump.	X	XX	
G.	All parallel pumps have check valves.	X	XX	
H.	Piping size increasers on the discharge side are installed between the pump and check valve.	X	XX	
I.	Check valves are not installed on suction piping unless there is a specific need.	X	XX	
J.	Horizontal suction lines have a gradual rise or slope to the pump suction to prevent air entrapment.	X	XX	
K.	Flange types and ratings are compatible with the connection device or equipment and pressure requirements. For example, raised-face (150-pound) flanges must not be combined with flat-faced (125-pound) flanges.	X	XX	XX

5. Cleaning, flushing and water treatment appears to be specified adequately

Checks:

		DD	CD	S
A.	Water quality treatment specifications adequately cover open and closed loop systems, including pre-startup flushing, cleaning and initial and follow-up treatment that is required until the building is turned over to the owner.	X	XX	XX

		DD	CD	S
B.	The specifications thoroughly describe the flushing and cleaning processes for heating hot water, chilled water, condenser water, domestic water and other fluid systems. These requirements include: specific minimum velocities to be achieved, duration of flush, number of flushes, cleaning chemicals used, use of fine construction strainers, what equipment or devices will be left out or piped around during the flush, number of strainers to be pulled for inspection, report requirements and final acceptance criteria. A typical velocity specification is: "Minimum flushing velocity in all pipe sections is the greater of 4 feet per second, or 1.5 times the velocity at design flow. If impractical to flush large diameter pipe at 2.5 fps velocity, clean in-place from inside by brushing and sweeping, then flush line at lower velocity."	X	XX	
C.	The specifications require the contractor to submit a flushing plan covering the specific procedures for this project and how they will flush by zone or floors, how proper velocities will be achieved, how piping that cannot receive design velocities will be cleaned, etc.	X	XX	XX

Resources

Avery, Gil. (1993) "Design and Commissioning Variable Flow Hydronic Systems," *ASHRAE Journal*. July 2003.

California Energy Commission. (2004) "Reference Specifications for Energy and Resource Efficiency." California Energy Commissioning website, http://www.energy.ca.gov/reports/2004-05-24_500-04-015.PDF. Accessed Dec 2006.

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McNally Institute. "Technical Information for Pumps and Seals." McNally Institute website, http://www.mcnallyinstitute.com/home-html/Technical_paper_index.html. Accessed Dec 2006.

17. Building and Space Pressurization Issues

Building pressurization control is essential for proper system functioning, and has a significant impact on occupant comfort and energy costs. In hot and humid climates, building pressurization is critical to ensure that moisture is not migrating through the envelope; contributing to the growth of mold. In cold or arctic climates, positive building pressure (with respect to outdoors) forces internally generated moisture towards exterior envelope components that may be cooled below the dew point with subsequent frost/freeze potential. There are many approaches to controlling building pressurization, and it is essential that the designer select an appropriate approach and clearly specify it in the basis of design and the construction documents.

There are three categories of building and space pressurization issues, each with a number of checks.

1. Building pressurization basis of design, control logic and setup procedures are specified, clear and effective.
2. The basis of design, control logic and setup procedures for pressure relationship between interior spaces are specified, clear and effective.
3. Building static pressure sensors are properly specified.

1. Building pressurization basis of design, control logic and setup procedures are specified, clear and effective

Checks:

		DD	**CD**	**S**
A.	A design narrative has been provided by the design engineer explaining the building pressurization objectives and strategy logic.	XX	XX	
B.	Specific set points are shown for dynamic building static pressure control. When not dynamically controlled, specific requirements are shown for setting up supply and return fan tracking differentials iteratively by checking building static pressure.	X	XX	
C.	Building pressurization problems have been addressed when operable windows exist (particularly near the ground level lobby where the inside pressure sensor is likely to be placed). This can be assessed by discussing the issue with the design engineer. The design must also ensure that the supply fan will not over-power the return fan. This will draw in outside air through the relief dampers when windows are open and the fan will go to minimum, in cases where building static pressure is controlled by modulating the return fan speed.	XX	XX	

		DD	CD	S
D.	Outside, return and relief air dampers have independent actuators and are not linked. This allows flows in each stream to be properly maintained without affecting the other air streams.	X	XX	
E.	Mixing plenums with significantly different static pressures in the return and outside air streams have been fitted with manual opposed blade dampers to artificially equalize static pressures so that mixing dampers can adequately control air flows without excessive noise or control positions out of controllable ranges.	X	XX	
F.	Test requirements are provided to verify, at worst case conditions, that pressure across lobby and egress doors does not exceed code (typically 0.15” WC), does not prevent openers/ closers from working properly, and does not whistle due to excessive infiltration/exfiltration rate.	X	XX	
G.	An adequately sized entry vestibule or revolving door is provided if it appears there will be occupants stationed near the entry doors (necessary even with active pressure control).	XX	XX	
H.	Elevator shaft vents have been fitted with smoke dampers arranged to fail OPEN if smoke is identified in the shaft, per ASHRAE Standard 90.1 requirements. This is especially important for high-rise structures.	X	XX	
I.	Fan coil units on exterior walls will not cause a negative pressure inside any wall or ceiling cavity, resulting in outside air being drawn into the cavity (only required in hot and humid climates). To accomplish this, all returns are ducted and there are no outside air intakes through the fan coil unit—outside air should be ducted directly to common corridors or to individual rooms. Penetrations through the fan coil unit casing are specified to have the openings completely sealed to prevent depressurization of the wall cavities.	XX	XX	
J.	All fan coil units above dropped or hard ceilings have fully ducted return air to minimize the potential for pulling air from locations that could be problematic (moist outside, contaminated inside sources) and from causing unwanted depressurizations in other spaces.	XX	XX	
K.	There are no filters on return air grills leading to ceiling plenums (dirty filters cause negative pressure in the ceiling plenum and can draw outside air into walls and ceiling cavities).	XX	XX	

		DD	CD	S
L.	Requirements are provided for contractor to fine-tune the static pressure control loop within the constraints of the equipment and sequences specified.	X	XX	

2. The basis of design, control logic and setup procedures for interior space pressurization are specified, clear and effective

Checks:

		DD	CD	S
A.	A design narrative is provided by the design engineer explaining the room pressurization objectives and strategy logic.	XX	XX	
B.	Specific set points are shown for dynamic pressure control with deadband ranges.	X	XX	
C.	Specifications require barrier walls built ‘deck to deck’ between pressure zones to be sealed and tested for design leakage rates.	XX	XX	
D.	Rooms with supply and exhaust air flow specified for maintaining pressure differential have balancing tolerance requirements that are offset so that improper flow relationships will not be realized, even at the worst case scenarios of the measuring error bands. (e.g. For positive rooms +10% / -0% for supply and +0% / -10% for exhaust. Negative rooms +10% / -0% for exhaust and +0% / -10% for supply.)	X	XX	
E.	All room penetrations above and below the ceiling (in walls and all penetrations in the walls, ceilings and floors) and the ductwork are required to be sealed. Door threshold and jamb seals may be required. Details are provided.	X	XX	
F.	For very critical rooms, surface mount or recessed vapor-tight or non-return-air tight fixtures are specified.	X	XX	XX
G.	For rooms with critical pressure differential requirements, a sliding door is preferred. If a swing door is used, it normally opens out of a negative room and opens in to a positive room to minimize “bad” air entering or leaving the room.	XX	XX	
H.	For very critical rooms an anteroom should be specified, if possible, with code or industry required air change rates and neutral pressure design or control.	XX	XX	
I.	Code minimum air change rates are specified.	X	XX	

		DD	CD	S
J.	Expect to see a minimum of 0.01” WC (2.5 Pa) required for room pressure differentials. Codes may require higher values.	X	XX	
K.	Check capacities and schedules to see that 400 cfm of differential flow into rooms of about 200 sq. ft. can be provided. If it is much less, query the engineer about their experience and assumptions.	X	XX	
L.	Test requirements include verifying pressure control at worst case conditions on both ends of supply and exhaust / return fan operation (e.g., when supply fan is at its minimum, verify the exhaust fan can turn down enough or OFF and when supply fan is at maximum, verify that the exhaust fan has sufficient capacity).	X	XX	
M.	For critical applications, pressure relationships for each room are specified (in the specifications or on a room pressurization floor plan drawing) with actual pressure differential values, not just by supply and return or exhaust flow rates. (Due to pressures in adjacent walls and ceilings, a room can be negative to certain adjacent spaces even though more ducted supply air is brought in that ducted return air.) Verify that specified pressurization values are reasonable given the type of construction. For example, maintaining 0.05” WC between rooms with dropped ceiling tiles isn’t reasonable.	X	XX	
N.	Cascading pressure differentials from different spaces do not conflict with the building envelope differential set point or stack effects. For example, an isolation room on an exterior wall is kept 0.05” WC negative to the interior corridor, but the interior corridor is maintained 0.02” WC positive to outside. This makes the isolation room 0.03” WC negative to the outside, which may result in moisture problems.	X	XX	
O.	Test requirements are included to fine-tune the flow differential settings during worst case conditions to meet the desired pressure relationship, in cases where active pressure differential control is not specified, and pressure relationships are based only on flow differentials.	X	XX	XX
P.	Requirements are provided for contractor to fine-tune the differential pressure control loop within the constraints of the equipment and sequences specified, including interactions with fume hoods and adjacent rooms.	X	XX	

3. Static pressure sensors are properly specified

Checks:

		DD	CD	S
A.	Sensor accuracy is specified with a narrow range around the expected values (-0.20 to +0.25” WC). Pressure critical areas (hospitals, labs, clean rooms, under floor air distribution systems, etc.) may require an increasingly narrow range.	X	XX	XX
B.	Pressure sensing tubes are provided, terminated at the exterior and interior with specifically designed pressure sensing heads to minimize ambient air and wind velocity effects. There are no open tubing ends. In very windy environments, the control system filters the pressure signal (as the signal noise can be significantly greater than the signal).	X	XX	XX
C.	Pressure sensing tube ends are not installed near sources of air movement or interior or exterior pressure other than ambient.	X	XX	XX
D.	In windy environments the designer has considered multiple outside sensors on different building cardinal faces with their tubing run to an accessible manifold for averaging and fine-tuning.	XX	XX	XX
E.	The designer has considered specifying multiple interior sensors in any tall atria or lobby and other sensors located more interior or on other floors to allow averaging or switching between sensors during the fine-tuning process.	XX	XX	XX
F.	When at all practical, the building control system network is not used to convey the building interior or exterior pressure signal. The pressure tubing is run directly to the control panel of the controlled device (relief damper or return fan controller). This is recommended to ensure the control loop speed is not slowed down excessively from high network traffic.	X	XX	XX

Resources

ASHRAE. (2003) *Selecting Outdoor, Return, and Relief, Dampers for Air-Side Economizer Systems*. ASHRAE Guideline 16P-2003.

ASHRAE. (2005) “Thermal and Moisture Control in Insulated Assemblies -Fundamentals,” *ASHRAE Handbook of Fundamentals*.

California Energy Commission. (2003) “Advanced Variable Air Volume System Design Guide.” CEC website, http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF. Accessed Dec 2006.

Stum, K., and Nelson, N. (2004) *Commissioning Building and Space Pressurizations - Start in Design*. Paper presented at the National Conference on Building Commissioning.

Wiseman, B. (2003) “Room Pressurization for Critical Environments,” *ASHRAE Journal*. February 2003.

18. Daylight Dimming Issues

The goals of lighting controls are to increase productivity and livability while minimizing energy consumption for the life of the building. Daylight dimming offers great potential for meeting these goals. Though daylight dimming is not a new technology, it is still prone to poor design and installation, resulting in systems that do not meet their design intent. Problems originate in the selection of equipment, application and design of the systems, and the specifications for installation. A thorough design review can mitigate design deficiencies and provide adequate support in the design for commissioning to be successful. Simply specifying the devices to be installed, as is typical in other aspects of lighting design, will not produce the working system desired in the design intent.

The following issues are important elements of the lighting control system. When reviewed during design phase, attention to these issues will increase the likelihood that the contractors install and set up lighting controls that perform per the design intent and that the operators will be able to maintain the system over time.

1. Design criteria and sequences of operation are clear and complete
2. Field set up and acceptance requirements are complete
3. Sensor position and quantity are properly specified and shown
4. Operation manuals and operator and staff training requirements are complete

1. Design criteria and sequences of operation are clear and complete

Checks:

		DD	CD	S
A.	Design intent defines the owner’s expectations for lighting levels, energy savings, training and occupant control.	XX		
B.	Basis of design provides documentation of lighting analysis (modeling and simulation), including photometric property and architectural structure assumptions, daylighting factors and lighting levels to meet design intent.	XX		
C.	Control circuits are parallel to the daylight contours so that control “zones” match daylight availability and coverage patterns.	X	XX	XX
D.	Dimming zones do not span different building exposures.	X	XX	XX
E.	Dimming zones have consistent window/glazing types and orientation (e.g., a single zone should not include east and south facing glass, or include an area with a tall window-wall and another with smaller windows).			
F.	Single sidelit (not skylit) zones do not reach too far into interior of building.	X	XX	

		DD	CD	S
G.	Potential shadows from surrounding buildings, trees, fences, and other objects at different times of the day and year are factored into zone design.	X	XX	
H.	Specifications provide the low limit of dimming required. This limit is appropriate given cost considerations. Ballasts dimming to 20% are much less costly than those required to dim down to 5% of maximum output and wiring schemes required for very low dimming are more costly.	X	XX	XX
I.	Ballasts and their wiring schemes are capable of dimming down to the designed low limit requirements.		XX	XX
J.	Functional user override features are included for dimming that return to automated control after a specific override time period.		XX	
K.	Requirements for time delay are noted in control specifications. (e.g., “The brightening or dimming response time when a cloud passes overhead is....”)		XX	XX
L.	Lights are dimmed to their lowest level, rather than shut off, when ambient light is greater than required levels. If lights are completely off, occupants sometimes think that the lights are broken.	X	XX	
M.	Requirements and assumptions related to the existence and operation of blinds, shades and curtain are integrated with the dimming criteria. Any controls are fully specified. For side lighting, the top level of glazing should have separate or no shading devices so light can reflect off of the ceiling. Automatic blinds, shades, and curtains are not controlled from light levels along with dimming, or cycling may result.	XX	XX	
N.	Ballast requirements for total harmonic distortion, power and crest factors are given for dimmed levels, not just for full output.		XX	XX
O.	A manufacturer’s extended warranty on fluorescent lamp ballasts is required (typically 3-5 years).		XX	XX
P.	A complete step-by-step sequence of operation is included defining the lighting levels (max and min), zones, interaction with occupants, interaction with occupancy and time-clock controls, and interaction with lighting on-off or dimming switches.	X	XX	X
Q.	Requirements for lighting level deadband adjustability are defined in equipment specifications. Rigid deadbands may not be large enough for the lighting variations.	X	XX	XX

		DD	CD	S
R.	Design criteria include clear exceptions on maximum ramping rates to increase equipment lifetime and reduce possibility that occupants will be bothered by changes in lighting levels.	X	XX	
S.	Architectural features (exterior shading, glazing coatings, window placement, prisms, light wells, light surfaces for reflection of light into the space) are included to reduce solar gain in summer and provide diffusion of light into the space and prevent glare. For example, side lighting ideally needs a high separate window for reflecting on the ceiling.	XX	XX	
T.	Interface with BAS or other lighting control systems is defined and is fully compatible for all features of the sequence required. Interface should be shown on lighting and controls drawings.	X	XX	XX
U.	Specification defines the amount of light to be gathered by the photo sensor in relation to its location for the lighted surface and this matches the application. For example, if 5 FC on the horizontal dark floor is the maintained lighting level and the sensor is mounted 15 feet off the ground, the sensor must be capable of detecting 5 FC from a dark floor at that distance.	X	XX	XX
V.	Field devices and controls are required to be labeled and easily accessible for maintenance.	X	XX	
W.	Wiring diagrams are provided of the controls to support the sequence of operation.		XX	
X.	Daylight dimming controls are properly integrated with emergency fixtures, using separate ballasts for dimming and emergency backup.	X	XX	

2. Field set up and acceptance requirements are complete

Checks:

		DD	CD	S
A.	Lighting level ranges at specific locations are included in drawings or specifications.	X	XX	
B.	Any required start-up and lamp burn-in procedures are included in dimming control and electrical equipment specifications. Some fluorescent lamps require a period of operation at full output prior to dimming to realize rated lamp life and output. Specifications should require programming of the dimming settings to be done after any required burn-in.	X	XX	

		DD	CD	S
C.	The acceptance criteria clearly specify the locations where light level measurements are to be taken. Lighting level requirements are specified at specific locations and orientation of surfaces, such as on a desk or on a vertical or horizontal surface, are a defined distance away from glazing, cubicle walls, and other light sources (computer monitor, task light --either on or off). The specification also clearly states the number of locations that are to be measured and whether every absolute reading must be within the specified range, or an average must be within the specified range with a maximum deviation from the design value.	XX	XX	
D.	Specifications state that sensor and dimming settings are set up and calibrated after furniture, final finishes and all lighting equipment are installed and operational.	XX	XX	
E.	Requirements for time of day lighting level measurements are included in acceptance requirements. Lighting level tests are required to be conducted at full sun, partial cloudy and full darkness.	XX	XX	
F.	Specifications require the contractor to provide fine-tuning of the system operating parameters after initial setup and 2-3 times during the first year for seasonal adjustments.	XX	XX	
G.	Initial start-up and calibration procedures are required to be provided by the manufacturer’s representative, not the contractor. (Electrical contractors generally do not have the expertise to provide this.) The contractor must provide the proposed and final start-up and calibration procedures to the commissioning authority for review.			

3. Sensor position and quantity are properly specified and shown

Checks:

		DD	CD	S
A.	The number of sensors specified is appropriate for the size of zone controlled by those sensors.	X	XX	X
B.	The locations of all photo sensors are shown on the plans. Height and position criteria are also shown. Photo sensors should not be installed in direct sunlight or in the direct light of lighting fixtures.	X	XX	X

		DD	CD	S
C.	Sensor orientation is correct for the application. Some sensors are to be installed perpendicular or parallel to light sources.	X	XX	X
D.	It is clear whether sensors are open or closed loop, and their mounting positions are shown correctly. Open loop sensors are pointed at entering light (window or skylight), and closed loop sensors are oriented to sense light from reflected surfaces.	XX		X
E.	Final sensor location is specified to be approved by the engineer and manufacturer and provided on final as-builts, and controls graphics interface if appropriate.		XX	X
F.	Sensors are specified to be placed so as to not be easily damaged by normal occupant activity.		XX	

4. Operation manuals and operator and staff training requirements are complete

Checks:

		DD	CD	S
A.	Requirements for O&M manuals include full setup, operation, recalibration, troubleshooting and maintenance procedures.	XX	XX	
B.	Requirements for training of operations staff are well-specified and appropriate. Requirements should state an adequate duration and require that instruction is provided by a qualified vendor, not the electrical contractor.			

Resources

Lawrence Berkeley National Laboratory. *Tips for Daylighting with Windows*. LBNL-39945

Energy Design Resources. "Energy Efficient Technologies - Daylighting Design." Energy Design Resources website, http://www.energydesignresources.com/category/daylighting/. Accessed Dec 2006.

Seattle Daylighting Lab website. http://www.daylightinglab.com/. Accessed Dec 2006.