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BUILDING TECHNOLOGIES PROGRAM

HVAC Controls Guide for Plans Examiners and Building Inspectors

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Contents

Introduction

The purpose of this guide is to provide an aid that will make it easier to apply the HVAC control requirements found in building energy codes. This guide addresses requirements defined by the following codes and standards, which are common bases for the codes that are adopted by state and local jurisdictions:

- The International Energy Conservation Code (IECC), versions 2009 and 2012.
- The American Society of Heating and Refrigeration Engineering Association (ASHRAE) Standard 90.1, versions 2007 and 2010.

Ensuring compliance with HVAC control requirements is a difficult task, as controls can be difficult to identify on plans or in the building. Yet it is a crucial task. HVAC controls are a key driver of building performance and without compliance and enforcement activities the code requirements may be ignored, overlooked, or misunderstood.

“Does the control system _______________?”
When it comes to verifying the proper implementation of certain HVAC controls, there’s simply no way a building inspector can do it alone. There are too many possible system configurations to understand and too little time. Recognizing this limitation, this guide aims to provide code officials with the background required to ask meaningful questions. For example:

- Does the control system include integrated economizer control?
- Does the control system prevent simultaneous heating and cooling?
- Does the control system reset the chilled water supply temperature based on demand?

Compliance can then be achieved using a mix of the suggested checks in this guide, good questions, and requests for the engineer or builder to show how the system complies.

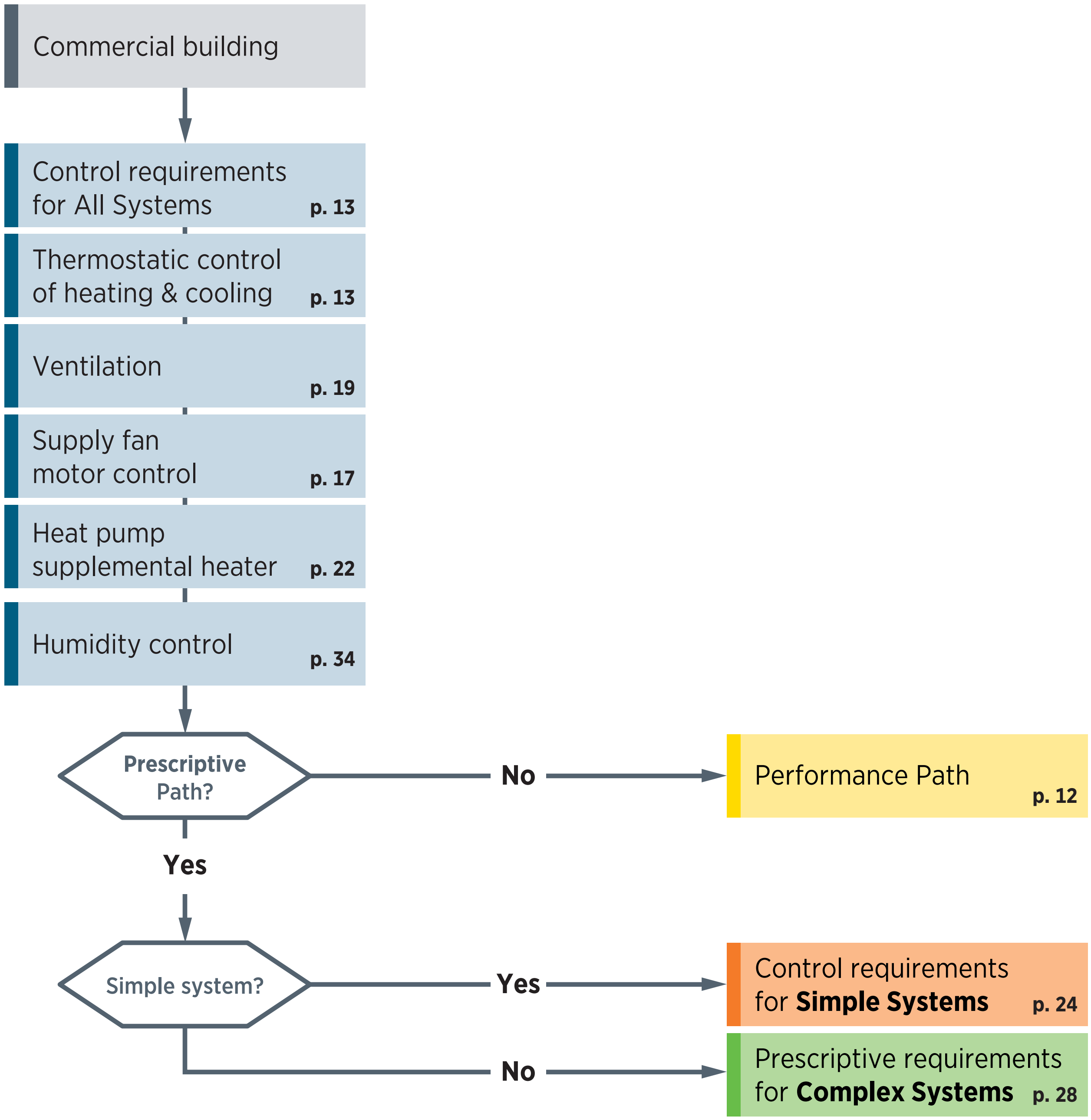
How to Use the Guide

At a basic level, the HVAC controls required by building energy codes are easy to understand. They make sure that equipment turns on when it is needed, off when it isn't, and that while operating it doesn't consume more energy than needed to make people comfortable in the building. In this guide, we describe the checks that plans examiners and building inspectors can make to ensure that these basic control features have been properly included in the building design.

This is a practical guide. Completing the checks defined in this guide will not guarantee that a building meets each specific HVAC control requirement. References to the relevant codes sections are provided to show where to look for additional detail, such as when exceptions are allowed. Nonetheless, performing the checks in this guide will go a long way toward ensuring that buildings include HVAC controls capable of providing a comfortable and healthy environment, while reducing energy waste.

Let's Begin!
For both plans review and inspection, the process begins with identifying the basic characteristics of the HVAC design. The figures below show which system characteristics must be understood in order to determine which code requirements apply to the building. A look at the mechanical floor plan will probably be enough to trace your way through the figures and arrive at the applicable requirements. You can then jump to the corresponding color coded sections of this guide. Each section explains the requirement and describes a method for checking compliance at plans review and at inspection.

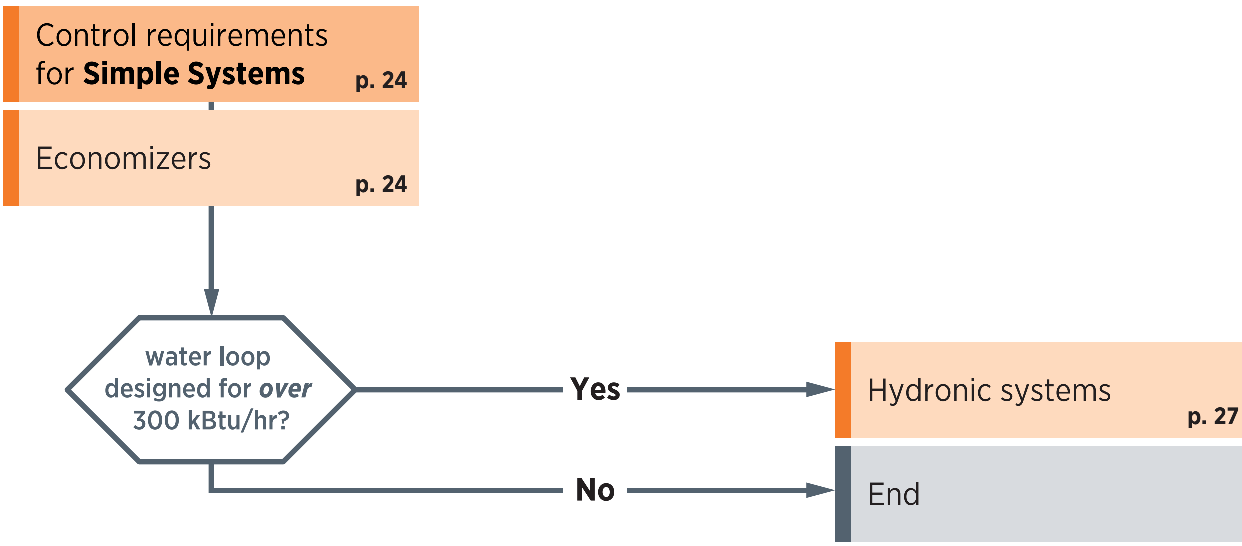
Note: The figures and control sequences presented in this guide are examples of what code officials may find. They are not intended to be used for design purposes.



Prescriptive — *An approach to satisfying the code requirements under which the design and construction must comply with the specific system and equipment parameters set forth in the code. This contrasts with the performance approach to compliance, under which a certain amount of flexibility in those parameters is allowed, so long as the building utilizes less energy than a reference design.*

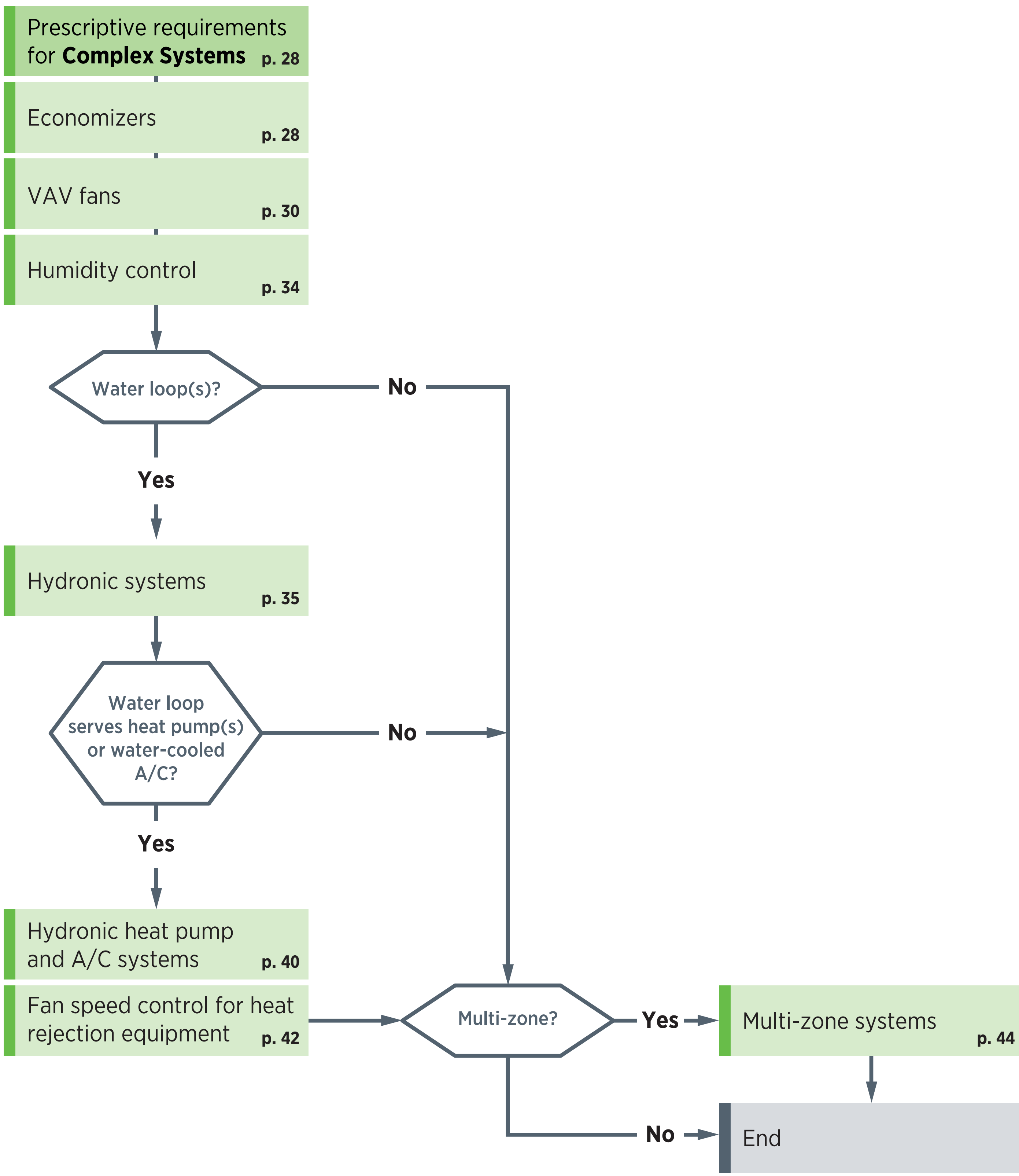
Simple system — *A system that utilizes factory-assembled HVAC equipment, called packaged or unitary equipment. In a simple system, one such unit is assigned to each zone. The exception to this is that the IECC also allows a heat-only system serving multiple zones to qualify as a simple system.*

Complex system — *Also sometimes referred to as built-up, these systems include various components — chiller, cooling tower, boilers, pumps, fans, and more — that are assembled on site to form the building HVAC system. Once assembled, the system may serve multiple zones with heating and cooling.*



Hydronic — *Using water. A hydronic system is one that circulates heated or chilled water through a loop to provide comfort in a* ***zone*** *or to provide the heat source or sink for HVAC equipment.*

Zones — *Portions of a building served with heating, cooling and ventilation. Zones have similar HVAC requirements and can therefore be served with a single thermostat or set of sensors and a single control strategy.*


Prescriptive requirements for **Complex Systems** p. 28
Economizers p. 28
VAV fans p. 30
Humidity control p. 34
Water loop(s)?
No
Yes
Hydronic systems p. 35
Water loop serves heat pump(s) or water-cooled A/C?
No
Yes
Hydronic heat pump and A/C systems p. 40
Fan speed control for heat rejection equipment p. 42
Multi-zone?
Yes
Multi-zone systems p. 44
No
End

Code Requirements and Compliance Checks

Performance Path

Many building energy codes allow buildings to satisfy the code requirements either by meeting each specific requirement or by demonstrating that the building performs as well or better than a reference building design that satisfies the specific requirements. Both ASHRAE 90.1 and the IECC offer a performance path to compliance. However, even buildings following the performance path must meet some mandatory requirements relating to HVAC controls.

Thermostatic control of heating and cooling and control of ventilation are required for all buildings; as are some controls relating to supplemental heaters in heat pumps, humidity and commissioning. These nearly universal requirements are discussed in the following section on control requirements for all systems. Later sections turn to requirements that may not be satisfied by buildings taking the performance path.

Control Requirements for All Systems

Thermostatic Control of Heating and Cooling

Thermostatic controls are required in each conditioned building zone. These devices must be capable of setting the zone's target temperature for heating and cooling. They must also prevent simultaneous heating and cooling of the zone and allow for a range of allowable temperatures, known as a deadband, in which neither heating nor cooling is provided. Finally, the thermostatic controls must allow the system to schedule unoccupied periods and occupied periods, allowing for a system start up period between. During the unoccupied period, heating and cooling target temperatures can be set back to conserve energy by allowing a greater range of space temperatures.

Plan Review

Suggested Compliance Check(s):

- Check mechanical floor plans to verify that there is at least one thermostat per distinct occupancy area (figure 1).

- Review the mechanical floor plans and mechanical schedule to locate control sequences and verify that the design engineer has specified deadband, set back and scheduling capabilities (figures 2-4).*

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 1: Mechanical floor plan showing thermostats in multiple locations

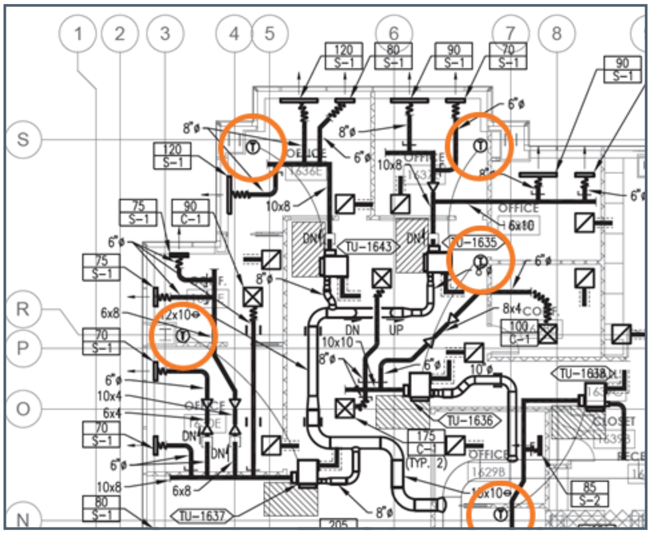


Figure 2: Control diagram for variable air volume (VAV) box demonstrating 5 degree deadband

Zone Temperature Control Sequence

- Heating set point (70°F), adjustable
- Cooling set point (75°F), adjustable
- Deadband of 5°F shall be maintained between heating and cooling set points

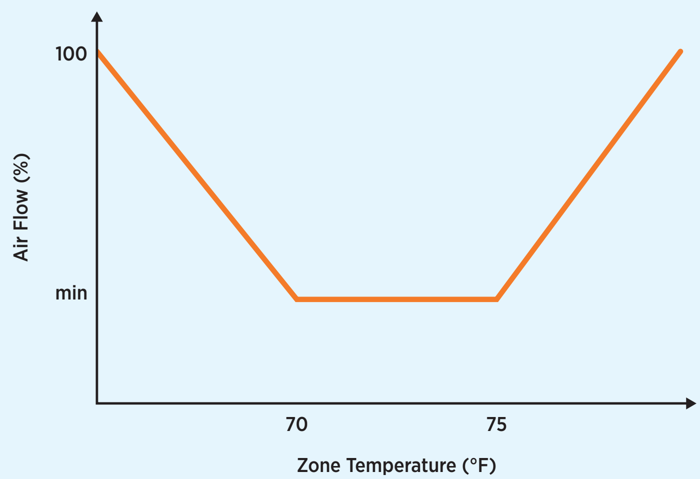


Figure 3: Sample control sequence showing setback capabilities

Unoccupied Mode:

1. Air handling units and terminal units will go to unoccupied mode when room occupancy sensors and schedule program define the zone(s) served to be unoccupied.
2. Zone temperature set point will reset to 55°F (heating mode) and 85°F (cooling mode).
3. Outside air damper in closed position.

Figure 4: Sample control sequence showing optimum start capabilities

> Optimum Start: The system shall calculate the time required to bring zones from the unoccupied temperature and humidity condition to occupied condition. This time shall be used to schedule the warm-up/cool-down period such that occupied conditions are achieved just prior to the scheduled occupied period.

Building Inspection

Suggested Compliance Check(s):

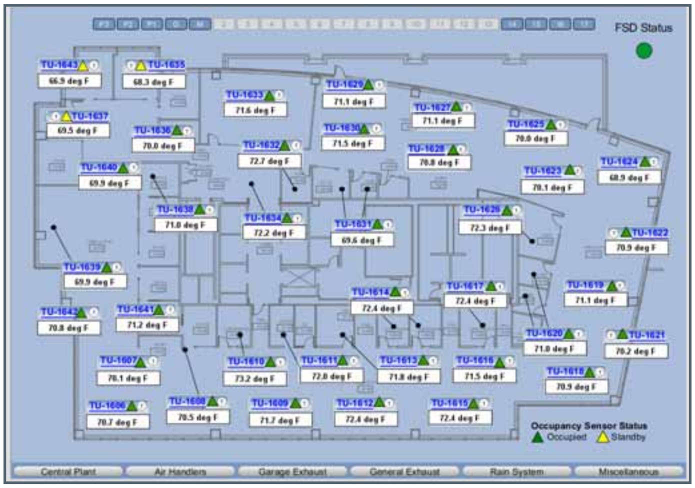
- Verify that programmable thermostats and temperature and humidity sensors have been installed as shown in the approved mechanical plans (figure 5 and 7).

- Confirm that the installed thermostats have deadband and setback capabilities. Single setpoint thermostats with a heat/cool/auto setting do not comply (figure 6).

Figure 5: Temperature sensor, as may be installed in a building with a building automation system

Figure 6: Programmable thermostat, as may be installed in building using packaged HVAC equipment

Figure 7: BAS screenshot showing temperature sensors measuring zone temperatures



Additional Detail:

a) Zoning

Each zone is required to have a dedicated temperature control device. If the HVAC system is designed to regulate humidity, then each zone must also have a humidity control device.

Code Sections

IECC	ASHRAE
2009: 503.2.4.1	2007: 6.4.3.1.1
2012: 403.2.4.1	2010: 6.4.3.1.1

b) Deadband

Temperature controls for each zone shall be capable of providing a range of 5 degrees above/below setpoint when no heating/cooling occurs. For example, a setpoint of 70°F for heating and 75°F for cooling provides a 5 degree deadband where no heating or cooling will occur.

Code Sections

IECC	ASHRAE
2009: 503.2.4.2	2007: 6.4.3.2, 6.4.3.1.2
2012: 403.2.4.2	2010: 6.4.3.2, 6.4.3.1.2

c) Thermostatic setback capabilities

Setback controls must be able to setback temperatures during unoccupied times to 55 for heating and 85°F or 90°F for cooling.

Code Sections

IECC	ASHRAE
2009: 503.2.4.3.1	2007: 6.4.3.3.2
2012: 403.2.4.3.1	2010: 6.4.3.3.2

d) Automatic setback and shutdown capabilities

Programmable thermostats shall be capable of different programs for different daily occupancy schedules. They must also retain information during power outage for 10 hours and have a temporary manual override option.

Code Sections

IECC	ASHRAE
2009: 503.2.4.3.2	2007: 6.4.3.3.1
2012: 403.2.4.3.2	2010: 6.4.3.3.1

e) Optimum start controls

The system controls shall be capable of varying the start time to bring each space up to setpoint immediately prior to scheduled occupancy. This optimum start capability recognizes that the system will require a variable amount of time to bring zones to comfortable conditions, depending on the building's unoccupied condition and the weather. Systems with a capacity less than 10,000 CFM may be exempt from this requirement.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.4.3.3.3
2012: 403.2.4.3.3	2010: 6.4.3.3.3

f) Zone isolation

Where multiple zones are served by a common HVAC system, but will be occupied on different schedules, the system must include controls that allow the unoccupied zones to be automatically isolated. When isolated, the HVAC system will neither supply nor exhaust air from the unoccupied zones.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.4.3.3.4
2012: NA	2010: 6.4.3.3.4

Supply Fan Motor Control

ASHRAE 90.1-2010 introduced a new requirement for variable airflow controls in the following types of equipment:

- Air handling and fan coil units served by chilled water and having a supply fan motor larger than 5 hp.
- Units serving a single zone and having direct expansion cooling capacity of more than 110,000 Btu/h.

Such equipment is required to use two speed motors or variable-speed drives on the supply fan.

Plan Review

Suggested Compliance Check(s):

- Review the fan schedule to see that large fans (5 hp and larger) are specified with variable speed drives or two speed motors.

Figure 8: Fan schedule indicating VSD to be provided

FAN SCHEDULE										
ID	Area	Type	Drive	CFM	T.S.P. (in H_2O)	Basis of Design	Max Wt. (lbs)	Electrical		Control
								Volt/Ph	HP	
PF-1	Stair	Utility set	Belt	8000	0.5		400	480/3	7.5	VFD
PF-4	Elevator	Utility set	Belt	10000	0.5		400	480/3	7.5	VFD
SF-1	Office	Vane axial	Belt	35000			200	480/3	40	VFD
RF-1	AHU-1	Vane axial	Belt	20000			200	480/3	25	VFD

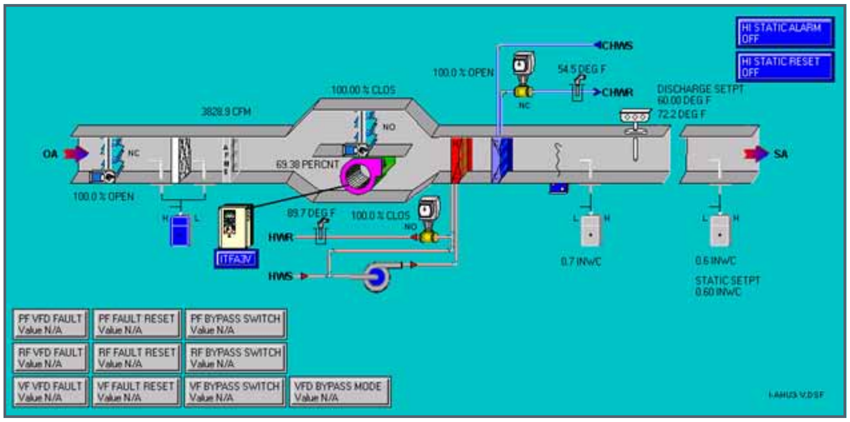
Building Inspection

Suggested Compliance Check(s):

- Verify that supply fans with motors greater or equal to 5 hp have been provided with VSDs (or other speed control devices) as indicated on the mechanical plans. Supply fans may be located on rooftops (simple systems) or mechanical rooms (complex systems) (figure 9). A building automation system (BAS) may also show where equipment is controlled by a VSD (figure 10).

Figure 9: VSD installed on a supply fan

Figure 10: BAS screenshot indicating VSD control of supply fan



Code Sections

IECC	ASHRAE
2009: NA	2007: NA
2012: NA	2010: 6.4.3.10

Ventilation

The basic requirement of controls relating to ventilation is that they be capable of reducing or shutting down ventilation when it is not required. Many systems are required to have motorized supply air and exhaust dampers that automatically open when the zone served is scheduled to be occupied and close when the zone is scheduled to be unoccupied. Systems with large ventilation requirements must also be capable of varying the amount of ventilation according with the real time needs of the zone.

Plans Review

Suggested Compliance Check(s):

- If the building is taller than three stories and in climate zones 4 through 8, verify that motorized dampers are specified for outside air and exhaust/relief dampers on the mechanical floor plans or mechanical schedule.

- Review the mechanical floor plans and mechanical schedule to locate control sequences and verify that the design engineer has defined a procedure whereby dampers will be closed and fans will be shut off when zones are unoccupied (figure 11).

- For large spaces (greater than 500 ft2), check the mechanical and electrical floor plans to see that CO_2 or other sensors are specified and tied in to the control system to enable demand control ventilation (DCV) (figure 12).

Figure 11: Sample control sequence showing damper control

> Outside Air Damper Control: Outside air intake dampers shall open in response to a start signal. The dampers shall close and the fan shall stop in response to any of the following: stop signal, loss of control signal, loss of electrical power, or the AHU supply fan motor stops.

Figure 12: Sample control sequence indicating DCV

> Demand Control of Ventilation: During occupied mode, zone requests for ventilation shall be determined based on signals from zone-located CO2 sensors. A zone shall request ventilation when the CO2 concentration exceeds 900ppm. In response to a request for ventilation, the system shall first increase the terminal unit airflow. If additional ventilation is required, the system shall then increase the outdoor air rate at the air handler.

Building Inspection

Suggested Compliance Check(s):

- Verify that outside air and exhaust/relief dampers have actuators that automatically open and close the dampers and that the dampers are in the closed position in spaces that are unoccupied (figure 13).

- Verify that CO_2 sensors included in the mechanical plans for the purpose of demand control ventilation have been installed as shown in the plans (figure 14).

- Review the mechanical plans and verify that automatic controls (i.e. occupancy sensor or manual timers) have been provided for ventilation fans larger than 3/4 hp as shown.

Figure 13: Motorized damper

Figure 14: Top view of CO_2 sensor (coin for scale)

Additional Detail:

a) Dampers

Outdoor air supply and exhaust/relief ducts shall have motorized dampers that automatically close when the spaces that they serve are not occupied. Buildings less than three stories tall or in climate zones 1 through 3 may use gravity dampers.

Code Sections

IECC	ASHRAE
2009: 503.2.4.4	2007: 6.4.3.4.3, 6.4.3.4.1, 6.4.3.4.2
2012: 403.2.4.4	2010: 6.4.3.4.2, 6.4.3.4.1

b) Ventilation fan controls

Fans with motors greater or equal to three-quarter horsepower, must have controls that can shut off fans when not required. This control may be an occupancy sensor, timer, or other device.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.4.3.4.5
2012: NA	2010: 6.4.3.4.4

c) Demand control ventilation

A control strategy that varies the minimum ventilation outdoor air based on occupancy is required for large, densely occupied spaces. This usually applies to spaces 500 square feet and larger that have an occupant load greater than or equal to 40 people per 1,000 square feet (IECC 2012 expanded the applicability by reducing the threshold occupant load to 25 people per 1000 square feet). Typically, ventilation is controlled by varying the outdoor air intake based on the measured level of carbon dioxide within a space.

Code Sections

IECC	ASHRAE
2009: 503.2.5.1	2007: 6.4.3.9
2012: 403.2.5.1	2010: 6.4.3.9

d) Heat recovery ventilation bypass

If a heat recovery ventilator (HRV) is installed, this HRV must not inhibit the operation of the economizer. This can be accomplished through controls which allow the HRV to be bypassed when the economizer is working.

Code Sections

IECC	ASHRAE
2009: 503.2.6	2007: 6.5.6.1
2012: 403.2.6	2010: 6.5.6.1

Heat Pump Supplemental Heater

If the building has heat pumps with supplemental electric heaters, those supplemental heaters should not be engaged until the heat pump's heating capacity is exceeded. ASHRAE 90.1 exempts heat pumps that are regulated under the National Appliance Energy Conservation Act (those with a cooling capacity less than 65,000 Btu/h) from this requirement.

Plan Review

Suggested Compliance Check(s):

- Verify that the mechanical schedule or control sequence specifies that supplemental resistance heating cannot operate when the heat pump can meet the heating load. This may be accomplished by specifying a multi-stage electronic thermostat programmed to initiate the supplemental heater when the heat pump cannot meet the setpoint (figure 15).

Figure 15: Sample heat pump control sequence showing auxiliary heat engaged as second stage

Mode	Call for Action	Signal to Heat Pump	Delivered Action
Heat	None	H	Reversing valve in heat position
	Stage 1 heat	H, H1	Heat using compressor
	Stage 2 heat	H, H1, H2	Heat using compressor and auxiliary heater

Building Inspection

Suggested Compliance Check(s):

- Check that the type of thermostat or building automation system specified in the approved mechanical submittal is installed and operating.

Additional Detail:

Code Sections

IECC	ASHRAE
2009: 503.2.4.1.1	2007: 6.4.3.5
2012: 403.2.4.1.1	2010: 6.4.3.5

Prescriptive Requirements for Simple Systems

Economizers

Economizers are required in most buildings to allow the HVAC system to increase the amount of outside air supplied to the zone if doing so will reduce energy consumption. This is possible, for example, when the zone is being cooled and the outside air is cool enough to meet part of that cooling demand. Control of the economizer should allow it to vary the supply of outside air from the minimum required ventilation to 100 percent outside air, based on the condition of the zone and the outside air. In simple systems, the economizer is likely to be integrated in packaged or unitary HVAC equipment. Thus, the economizer control strategy is likely to be found in the specifications for that equipment.

Plan Review

Suggested Compliance Check(s):

- Check the mechanical schedule to verify that economizers are specified for systems that are larger than the thresholds shown in the table below (figure 16).

IECC 2009	54,000 Btu/h in all climate zones except 1A, 1B, 2A, 7, and 8
IECC 2012	33,000 Btu/h in all climate zones except 1A and 1B
ASHRAE 2007	65,000 Btu/h in climate zones 3B, 3C, 4B, 4C, 5B, 5C and 6B 135,000 Btu/h in climate zones 2B, 5A, 6A, 7 and 8
ASHRAE 2010	54,000 Btu/h in all climate zones except 1A and 1B

- Locate control sequences and verify that the economizer control sequence meets the following requirements (figure 17):

  1) The supply of outside air varies from the minimum requirement to 100 percent.

  2) Economizers are sequenced with the mechanical cooling equipment and continue to function until the shut-off condition described in requirement 4, below, is reached.

  3) Economizers are not controlled only by mixed air temperature.

4) The supply of outside air is reduced to the design minimum when one of the following conditions applies:

- Outside air temperature exceeds:
  - 75°F in climate zones 1B, 2B, 3B, 3C, 4B, 4C, 5B, 5C, 6B, 7, or 8
  - 70°F in climate zones 5A, 6A, or 7A
  - 65°F in any other climate zone
- The climate specific shut off condition is reached, as determined by another approved approach from the code sections referenced in section c below.

Figure 16: Economizer specified on mechanical schedule

Air Handling Units		
Symbol Location Served		AHU-1 1st Floor Offices
Supply Fan	Type	Centrifugal
	Configuration	Fan Coil
	Air flow (CFM)	6,000
	Min air flow (CFM)	6,000
	Min outside air (CFM)	600
	HP: Motor	5
	Voltage/Phase	460/3
	Control	ON/OFF
	Isolation	Internal
Cooling Capacity	Nominal Tons	15
	Total (MBH)	171
	Sensible (MBH)	137
	EDB (°F)	76
	EWB (°F)	63
	LDB (°F)	55
	LWB (°F)	54
	CW Flow (GPM)	30.0
	ENT Water Temp (°F)	44.0
	LVG Water Temp (°F)	56.0
Heating	Type	None
Weight	LBS	3,000
Unit Electrical	MCA	8.3
	Voltage/Phase	460/3
Basis of Design	Manufacturer	Trane
	Model	T Series
	Notes	1
NOTE: Provide with factory installed 0–100% economizer controls without barometric relief.		

Figure 17: Economizer control sequence

AHU—1 & 2 Automatic Dampers

- Outside Air Damper
  - Modulating
  - Closed when AHU is not operating.
  - Controlled by space temperature, time of day, outside air temperature, and ventilation requirement
  - Economizer cycle:
    - Operates when outside air temperature is <= 75°F
    - Modulates between minimum outside air and free cooling

Building Inspection

Suggested Compliance Check(s):

- Verify that economizers have been provided on cooling equipment (e.g. heat pumps and rooftop units) as shown in the approved mechanical design (figure 18).

- To the extent possible, verify that the unit has the control capabilities needed to execute the control sequence in the approved mechanical design. This might be possible by examining the unit's local control panel or by consulting the manufacturer's specifications.

Figure 18: Economizer on a rooftop unit

Additional Detail:

a) Range of operation

Economizers shall be capable of operating at 100 percent outside air, even if additional mechanical cooling is required to meet the cooling load of the building. This strategy is known as integrated economizer control.

Code Sections

IECC	ASHRAE
2009: 503.3.1	2007: 6.5.1.3
2012: 403.3.1	2010: 6.5.1.3

b) Control strategy

Economizers must not be controlled only by mixed air temperature and must be able to be sequenced with mechanical cooling equipment. ASHRAE provides an exception for systems controlled from space temperature, such as single zone systems.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.1.1.2
2012: 403.1.1.2	2010: 6.5.1.1.2

c) High limit shutoff

When increase in outdoor air will no longer reduce cooling energy use, economizers must be able to reduce outdoor air to the design minimum.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.1.1.3
2012: 403.3.1.1.3	2010: 6.5.1.1.3

Hydronic Systems

The requirements for hydronic systems mainly apply to buildings with a complex, built up HVAC design. However, the IECC includes some control requirements for large (>300,000 Btu/h) systems that are categorized as simple systems. One example of such a system is a boiler loop that supplies hot water for radiant heating in a large apartment building. Such simple, but large hydronic systems are required to comply with the applicable hydronic system controls that are discussed in the next section of this guide.

Additional Detail:

Code Sections

IECC	ASHRAE
2009: 503.3.2	2007: NA
2012: 403.3.2	2010: NA

Control Requirements for Complex Systems

Economizers

The requirements for economizers in complex systems are similar to those for simple systems. The economizer must vary the supply of outside air from the minimum required ventilation to 100 percent outside air, based on the condition of the zone and the outside air. Despite this similarity, there are two reasons for providing a separate discussion of economizers for complex systems. First, there is an additional requirement for complex systems that the use of the economizer should not increase building heating. Second, the specification of the economizer in the design submittal is likely to look somewhat different and therefore the compliance check will be slightly different.

Plan Review

Suggested Compliance Check(s):

- Check the mechanical schedule to verify that economizers are specified for systems that are larger than the thresholds shown in the table below.

IECC 2009	54,000 Btu/h in all climate zones except 1A, 1B, 2A, 7, and 8
IECC 2012	33,000 Btu/h in all climate zones except 1A and 1B
ASHRAE 2007	65,000 Btu/h in climate zones 3B, 3C, 4B, 4C, 5B, 5C and 6B 135,000 Btu/h in climate zones 2B, 5A, 6A, 7 and 8
ASHRAE 2010	54,000 Btu/h in all climate zones except 1A and 1B

- Locate control sequences and verify that the economizer control sequence meets the following requirements (figure 19).*

    1) The supply of outside air varies from the minimum requirement to 100 percent.

    2) Economizers are sequenced with the mechanical cooling equipment.

    3) Economizers are not controlled only by mixed air temperature.

4) The supply of outside air is reduced to the design minimum when one of the following conditions applies:

- Outside air temperature exceeds:
    - 75°F in climate zones 1B, 2B, 3B, 3C, 4B, 4C, 5B, 5C, 6B, 7, or 8
    - 70°F in climate zones 5A, 6A, or 7A
    - 65°F in any other climate zone
- The climate specific shut off condition is reached, as determined by another approved approach from the code sections referenced in section c below.

5) The economizer will reduce outside air to the minimum requirement when outside air no longer provides cooling or when the system is in a heating mode.

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 19: Economizer control strategy shown in a control sequence

Modulating Economizer

- Controls position of a damper based on the Control State, Outside Air Temperature (OAT), and Cooling Demand.
- Economizer available if:
    - Cooling mode and fan on
    - Econ. low limit temp SP < OAT < Econ. temp SP
- When available, economizer:
    - Locks out other cooling when Cooling Demand < 25%
    - Modulates from minimum to maximum position as Cooling Demand increases from 0% to 25%

Building Inspection

Suggested Compliance Check(s):

- Review the mechanical plans and verify that economizers have been provided on air handlers as shown in the approved mechanical design.
- Confirm that economizer operation is controlled as specified in the approved mechanical design. This will often mean confirming that a building automation system has been installed and connected to the economizer.

Additional Detail:

a) Range of operation

Economizers shall be capable of operating at 100 percent outside air, even if additional mechanical cooling is required to meet the cooling load of the building. This strategy is known as integrated economizer control.

Code Sections

IECC	ASHRAE
2009: 503.4.1	2007: 6.5.1.3
2012: 403.4.1.1	2010: 6.5.1.3

b) System integration

Economizers should be used for cooling, even if supplemental mechanical cooling is required.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.1.3
2012: 403.4.1.3	2010: 6.5.1.3

c) High limit shutoff

When increase in outdoor air will no longer reduce cooling energy use, economizers must be able to reduce outdoor air to the design minimum.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.1.1.3
2012: NA	2010: 6.5.1.1.3

d) Heating impact

Use of the economizer must not result in an increased use of building heat.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.1.4
2012: 403.4.1.4	2010: 6.5.1.4

Variable Air Volume (VAV) Fans

VAV fans with motors larger than 10 hp (7.5 hp under IECC 2012), must be driven by variable speed drives, use vane-axial fans with variable-pitch blades, or incorporate controls such that motors use at most 30% of the design fan power when the system delivers 50% of the design air volume. The most common means of meeting this provision is with a variable speed drive controlled by a static pressure sensor located in the supply air duct. The pressure measured by the sensor is used to set the speed of the drive, and the sensor must be positioned well down the duct from the fan to provide good feedback. As heating or cooling demand decreases in the zones served, the dampers that control the supply of conditioned air to those zones will begin to close. As they close, the pressure in the duct increases. The sensor measures this increase and signals the drive to slow until the static pressure setpoint is achieved.

When the zone dampers are controlled by digital controls, the system efficiency should be further increased by resetting the static pressure setpoint pressure lower, until the damper serving the zone with the greatest demand is almost fully open. The control of VAV fans through this method is an important and somewhat complicated part of the HVAC control design strategy. However, verifying compliance with the code requirements requires only a few steps.

Plan Review

Suggested Compliance Check(s):

- Check the mechanical floor plan and mechanical schedule to see that large VAV fans are specified with VSDs or are vane-axial fans with variable-pitch blades (figure 20).
- If a direct digital control (DDC) system is specified on the plans, then locate control sequences and verify that the design engineer has defined a pressure reset strategy. In the strategy, the speed of the drive, often stated as a percentage, should be related to the operation of a remotely located zone box or "terminal unit" (figure 21).*
- Check the mechanical and electrical floor plans to verify that a pressure sensor is specified to be located in the supply air duct, well away from the supply fan (figure 22).

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 20: VSD specified on mechanical schedule

Remarks

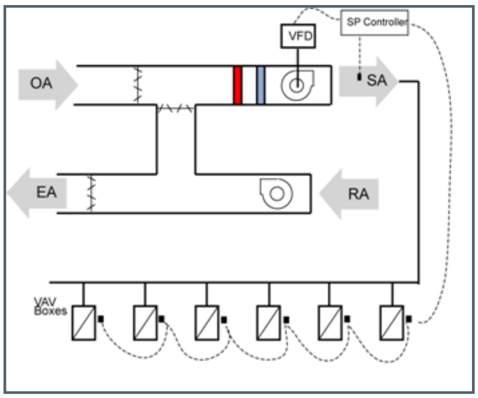
- Split system HVAC unit, suspended air handler, max height 48"
- Hot water heating coil with 2-way control valve sized for coil performance
- **Variable frequency drive supply fan with variable air volume pressure control**
- 100% outdoor air integrated economizer with differential dry bulb control
- Air flow meter
- Factory installed DDC controls with selectable protocol
- Remote controls interface
- Premium efficiency motors
- Low leakage dampers

Figure 21: Pressure reset strategy shown in control sequence

Supply Fan Control via Static Pressure Control: Controller shall modulate supply fan VFD speed to maintain static pressure setpoint.

- Initial static pressure setpoint shall be 0.75in H_2O.
- AHU controllers shall be networked with their associated terminal units.
- The static pressure setpoint shall be reset lower, until all airflow requests are satisfied and the damper on one terminal unit is wide open.
- The DDC controller shall modulate fan speed to maintain the duct static pressure setpoint. As duct pressure decreases, fan speed will increase. As duct pressure increases, fan speed will decrease.

Figure 22: Illustration of VSD (here VFD) control based on static pressure sensor and zone dampers

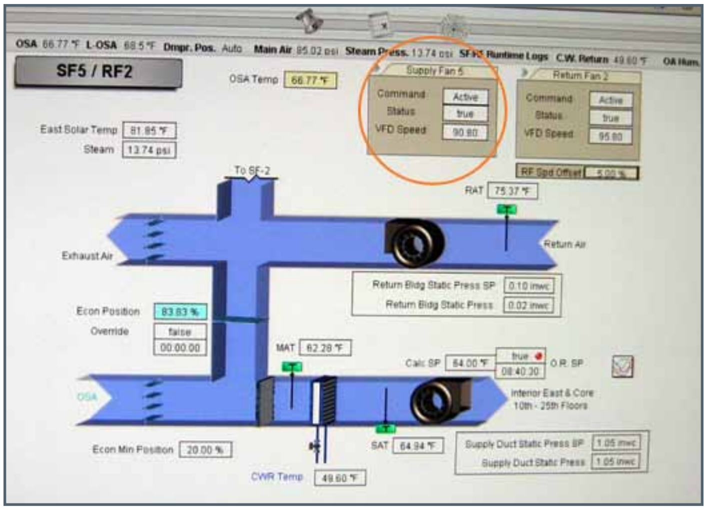


Building Inspection

Suggested Compliance Check(s):

- Verify that VSDs (or variable pitch vane-axial fans) have been installed as shown in the approved mechanical design.
- Confirm that static pressure sensor(s) have been installed as shown in the approved mechanical design.
- If the control sequence in the approved submittal included static pressure reset, check that the corresponding control system (most likely a building automation system) is installed and operational (figure 23).

Figure 23: BAS screen shot indicating control of VSD controlling supply fan based on static pressure



Additional Detail:

a) VAV fan control

Individual VAV fans greater than or equal to 10 horsepower in size must have a VSD, a vane-axial fan with variable-pitch blades, or other means to control airflow that use 30% or less of the design fan power to deliver 50% of the design airflow. Systems with digital control for individual zones must reset the drive speed to meet the need of the zone requiring the highest supply fan pressure. The IECC 2012 expanded the applicability by reducing the threshold fan size to 7.5 horsepower.

Code Sections

IECC	ASHRAE
2009: 503.4.2	2007: 6.5.3.2.1
2012: 403.4.2	2010: 6.5.3.2.1

b) Static pressure sensor location

Where static pressure sensors are used to control VAV fans, they must be positioned so that the pressure setpoint based on the sensor is no more than one-third the total design static pressure of the supply fan. Typically, this means the sensor must be positioned closer to the farthest zone supplied than to the fan. Each major duct branch should have at least one sensor.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.3.2.2
2012: 403.4.2.1	2010: 6.5.3.2.2

c) VAV fan pressure reset strategy

If direct digital control of individual zone boxes reports to central control panel, then a static pressure reset strategy must be included in the controls. Reset must to be based on the zone requiring the highest supply pressure.

Code Sections

IECC	ASHRAE
2009: 503.4.2	2007: 6.5.3.2.3
2012: 403.4.2.2	2010: 6.5.3.2.3

Humidity Control

Where humidifiers or dehumidifiers are provided, the system must control their operation to prevent simultaneous humidification and dehumidification and to shut off the components when they are not required.

Plan Review

Suggested Compliance Check(s):

- If the system has a humidifier with a preheat jacket, then confirm on the mechanical floor plan that a valve is shown on the hot water supply line feeding the preheat jacket.
- Verify that control of the preheat valve is described as a note on either the mechanical schedule or mechanical plans.*
- Verify that the control sequence specifies a means to prevent simultaneous humidification and dehumidification.*

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Building Inspection

Suggested Compliance Check(s):

- Where applicable, verify that an automatic valve has been installed on humidifier preheat jackets.
- Verify that simultaneous humidification and dehumidification has been prevented in accordance with the approach defined in the approved mechanical design.

Additional Detail:

a) Humidifier shutoff

Humidifiers with preheating jackets mounted in the airstream shall be provided with an automatic valve to shut off preheat when humidification is not required.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.4.3.6
2010: 6.4.3.6	2012: NA

b) Simultaneous humidification/dehumidification

Limit switches, mechanical stops, or other means of control, such as a sequence of operations, must be included that are capable of preventing simultaneous humidification and dehumidification.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.4.3.7
2012: NA	2010: 6.4.3.7

Hydronic Systems

HVAC systems often operate at peak capacity for only a small portion of the heating and cooling season. Energy codes require that hydronic systems be provided with controls to reduce the system's energy consumption when operating at less than peak capacity. This is achieved through equipment sequencing, reducing the pumping of fluid through the system, and by resetting the temperature of the hot water and chilled water supply.

Plan Review

Suggested Compliance Check(s):

- Review the boiler specifications in the mechanical schedule to verify that large boilers are required to have multistaged or modulating burners.
- If multiple boilers are specified, check the control specifications to confirm that they will be linked to a common control system (figure 24).*
- For large systems (see additional details below), check mechanical schedules to verify that VSDs or multi-staged pumps are provided for the pumps. Differential pressure sensors should also be specified, to provide the necessary feedback to the controls (figure 25).
- Review control sequences to ensure that a supply water temperature reset is included (figure 26).*
- For heated and chilled water systems with one shared distribution network (a 2-pipe system), review control sequences to verify that the system does not switch between heating and cooling without an outside air temperature change of at least 15 degrees and that controls can prevent such a switch without a 4 hour interval (figure 27).*
- Verify that language is included in control sequences for boilers and chillers to reduce flow through the plant when capacity is reduced (figure 28).*

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 24: Sample control sequence indicating that boilers are sequenced and modulate

Hot Water Pump Operation:

- Pumps operate in lead/lag fashion.
- Upon initiation of system operation, start lead pump.
- Lead pump VFD speed modulates to maintain heating water system differential pressure setpoint (20 psid, adjustable).
- During low load condition, flow is maintained through lead boiler at all times.
- Isolation valve on standby boiler is closed when standby boiler is off.

Figure 25: Sample boiler pump sequence of operations demonstrating variable flow capabilities/VSD

Boiler Sequencing:

- When flow is sensed from A to B in the crossover line, the DDC shall start primary boiler and hot water pump.
- Manufacturer controls will modulate the burner valve to maintain boiler hot water temperature.
- When load increases to the point that flow is again sensed from A to B in the crossover line, the DDC shall start standby boiler.
- As load decreases, the DDC shall stage boilers off in reverse order.

Figure 26: Sample control sequence indicating supply water temperature is reset

Chilled Water Setpoint (CHWST) Reset

- The default CHWST is 44°F.
- When the speeds of pumps on the secondary loop are at the minimum, start CHWST reset.
- CHWST will be reset proportionally between 48°F and 42°F:
  - 48°F; all cooling coil valves are less than 90% open.
  - 42°F; 3+ cooling coil valves are more than 90% open.
- Continue CHWST reset until the speed of one or more pumps on the secondary loop exceeds the minimum.

Figure 27: Illustrated control sequence for two pipe changeover

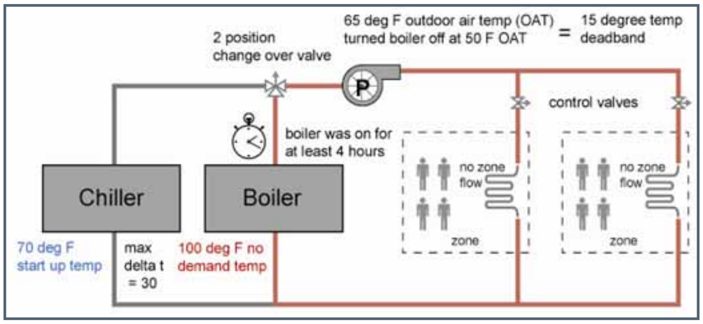


Figure 28: Sample control sequence for pump isolation

Chilled Water Pump Sequencing:

- In Cooling Mode, DDC shall start one system pump which shall run continuously.
- System pump variable speed drive will modulate to maintain the differential pressure setpoint (20 psid, adjustable).
- Second system pump will start if the differential pressure falls below the setpoint.
- When both pumps operate, they shall modulate at the same speed to achieve the differential pressure setpoint.
- When the system flow falls to 50% of design flow, the second pump shall turn off.

Building Inspection

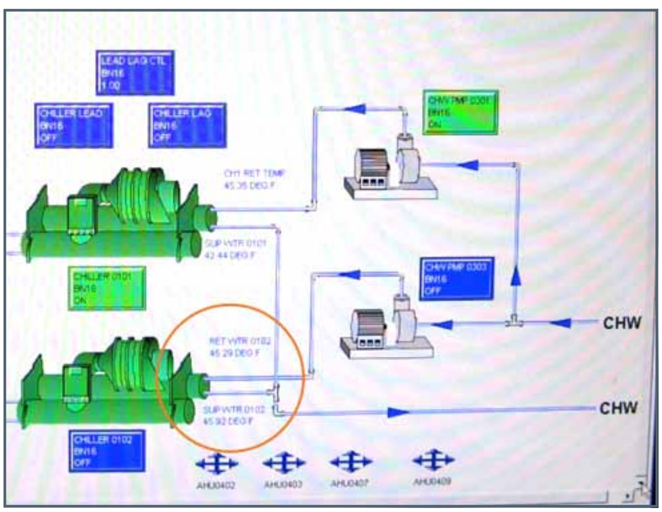
Suggested Compliance Check(s):

- Confirm that multiple boilers are connected to a common control system, such as a building automation system, and that boilers with greater than 500,000 btu/h capacity are equipped with multistage or modulating boilers (figure 29).
- Confirm that pump speed controls (e.g. variable speed drive or multiple-staged pumps) shown in the approved mechanical design have been installed on all pumps (figure 30).
- Verify that temperature sensors have been installed on chilled water supply, chilled water return, hot water supply and hot water return pipes (figure 31).
- Verify that the approved approach for controlling supply water temperature reset, typically a building automation system, is installed and operational (figure 31).

Figure 29: Linked boiler controllers

Figure 30: Multiple pumps with flow control

Figure 31: BAS showing temperature sensors on supply and return piping



Additional Detail:

a) Boiler sequencing

Heating systems made up of multiple boilers must be able to be sequenced, such that boilers can be automatically shut off as they are no longer needed to meet the heating requirement. Similarly, systems with one large boiler (greater than 500,000 btu/h input capacity) must have a burner that is either multistaged or modulating.

Code Sections

IECC	ASHRAE
2009: 503.4.3	2007: NA
2012: 403.4.3	2010: NA

b) Variable flow

Both IECC and ASHRAE require controls capable of reducing pump flow in large hydronic systems by at least 50% using VSDs or multi-stage pumps when the system is operating under part load conditions. However, the threshold of application differs. IECC requires such controls for systems with capacity greater or equal to 300,000 Btu/h. ASHRAE requires the controls for systems with individual pump motors larger than 5 horsepower or total pump system power greater than 10 horsepower.

Code Sections

IECC	ASHRAE
2009: 503.4.3.4(2)	2007: 6.5.4.1
2012: 403.4.3.4(2)	
2010: 6.5.4.1	

c) Supply water temperature reset

Systems with a design heating or cooling capacity greater than 300,000 Btu/h must include controls capable of resetting the supply water temperature according to the heating or cooling demand. The return water temperature or outside air temperature may serve as indicators of this demand. ASHRAE provides an exception for variable flow systems.

Code Sections

IECC	ASHRAE
2009: 503.4.3.4	2007: 6.5.4.3
2012: 403.4.3.4	2010: 6.5.4.3

d) Two-pipe changeover

Systems that provide heated and chilled water to zones using a single supply and return loop must have controls that prevent the initiation of heating within four hours of cooling, or the reverse. In addition, the change from heating to cooling, or the reverse, should be separated by a difference in outside air temperature of at least 15 degrees. The heated and chilled water supply temperatures at changeover should be less than 30°F apart.

Code Sections

IECC	ASHRAE
2009: 503.4.3.2	2007: 6.5.2.2.2
2012: 403.4.3.2	2010: 6.5.2.2.2

e) Pump isolation

Chilled water and boiler plants with multiple chillers or boilers must be able to reduce flow through system when a chiller or boiler is turned off.

Code Sections

IECC	ASHRAE
2009: 503.4.3.5	2007: 6.5.4.2
2012: 403.4.3.5	2010: 6.5.4.2

Hydronic Heat Pump and Unitary Air Conditioning Systems

Systems that employ a water loop to provide a source or sink of heat for heat pumps or unitary air conditioners are required to have controls to vary the flow of water through the system as a function of demand.

Plan Review

Suggested Compliance Check(s):

- Review the piping diagram to verify that two position valves are shown on the water loop of hydronic heat pumps and water-cooled air conditioners that can shut off circulation of water to the compressor of each individual heat pump or air conditioning unit (figure 32).

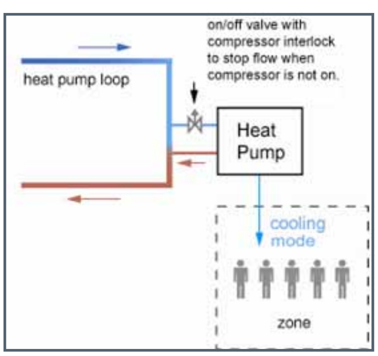
- Verify that the control sequences allow a water supply temperature deadband of 20°F between initiation of heat rejection and heat addition on the water loop.*

- Review the mechanical plans to verify that when the system is not in cooling mode circulation of water to the tower will be prevented by an automatic valve or a controlled pump, or that positive closure dampers are provided to stop air circulation through a closed circuit tower.

- Check mechanical schedule or control sequences to verify that the pumps serving hydronic heat pump water loops have been provided with VSDs.

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 32: Illustration of heat pump piping showing location of two position valves



Building Inspection

Suggested Compliance Check(s):

- Verify that two position valves have been installed on hydronic heat pumps and water cooled air conditioners, as shown on the approved mechanical piping diagram (figure 33).

- Verify that the pumps serving hydronic heat pump water loops have been provided with VSDs, where shown on the approved mechanical plans.

- Verify that heat loss through cooling towers is controlled using automatic valves, pumps, or positive closure dampers, as shown in the approved mechanical design.

Figure 33: Two position (open/close) valve with electric actuator

Additional Detail:

a) Two-position valve

IECC 2012 requires two position valves on hydronic heat pumps where the total hydronic system pump power is greater than 10 hp.

ASHRAE requires two position valves on hydronic heat pumps and water cooled air conditioners. ASHRAE 2007 provides an exception when total hydronic system pump power is less than 5 hp.

Code Sections

IECC	ASHRAE
2009: NA	2007: 6.5.4.4.1
2012: 403.4.3.3.3	2010: 6.5.4.4.1

b) Deadband

Hydronic heat pump water loops shall have controls that can provide a water supply temperature deadband of at least 20 degrees F between initiation of heat rejection (cooling tower) and heat addition (boiler).

Code Sections

IECC	ASHRAE
2009: 503.4.3.3.1	2007: 6.5.2.2.3(a)
2012: 403.4.3.3.1	2010: 6.5.2.2.3(a)

c) Heat rejection

To prevent excessive hydronic loop heat loss, control of heat rejection equipment (i.e. cooling towers) is required for climate zones 3-8. This control can be achieved using an automatic valve to bypass the tower or by turning off the circulation pump on an open-circuit tower serving a heat exchanger. For closed-circuit towers, it can also be achieved with low leakage positive closure dampers that prevent air circulation through the tower. In zones 5-8, the IECC requires use of a heat exchanger, circulation pump, and an automatic valve.

Code Sections

IECC	ASHRAE
2009: 503.4.3.3.2	2007: 6.5.2.2.3(b)
2012: 403.4.3.3.2	2010: 6.5.2.2.3(b)

d) Variable speed control

ASHRAE 2010 reduced the threshold for requiring variable speed control is required on hydronic heat pump and unitary air conditioner water loops to a total pump system power of 5 hp. This is lower than the 10 hp threshold that applies to all types of hydronic systems.

Code Sections

IECC	ASHRAE
2009: NA	2007: NA
2012: NA	2010: 6.5.4.4.2

Fan Speed Control for Heat Rejection Equipment

Controls are required on large fans used in cooling towers and air cooled condensers. Each fan powered by a motor of 7.5 hp or larger must have a device (e.g. VSD) that can control fan speed. Fan speed must control either the temperature of the fluid leaving the heat rejection device or the condensing temperature of the heat rejection device.

Plan Review

Suggested Compliance Check(s):

- Review the mechanical schedule to verify that fans with motor 7.5 hp or greater is provided with a VSD (or other means) to reduce fan speed (figure 34).

- Review the control sequences to verify that fan speed is used to control the leaving temperature of the fluid or the condensing temperature or pressure (figure 35).*

* If the building is equipped with a building automation system (BAS), then these capabilities will most likely be provided by the BAS. The BAS specifications or manual should indicate that the required capabilities are present.

Figure 34: Mechanical schedule showing cooling tower fans equipped with VSD

COOLING TOWER		
Symbol Location Served		CT-1 Chiller
Heat Rejection	Tons	800
Type	Cells	1
	Discharge	Vertical
Fluid	EWT (°F)	90
	LWT (°F)	77
	Flow (GPM)	1,500
	Ambient (°F)	67
	Nozzle (ft WG)	4
	Fluid	Water
Fan	Type	Axial
	Number	1
	Air flow (CFM)	170,000
	Motor HP	25
	Control	**VFD**
	Voltage/Phase	460/3
Basin Heater	Number	1
	Capacity	12
	Voltage/Phase	460/3
Pipe Connections	Supply (in)	10
	Return (in)	14
	Make-up (in)	2
	Drain (in)	1 ½
	Overflow (in)	3
Weight	LBS	31,000
Basis of Design	Manufacturer	ABC Inc
	Model	Model XYZ
Notes		

Figure 35: Sample note on mechanical schedule

NOTE: Cooling tower fan VFD modulates speed to maintain condensing water temperature setpoint.

Building Inspection

Suggested Compliance Check(s):

- Verify that fans 7.5 hp and greater have been provided with devices for fan speed control (e.g. VSD) (figure 36).

- Confirm that the means of controlling fan speed identified in the approved mechanical design, typically a building automation system, has been installed and is operational.

Figure 36: Cooling tower motor — check for connection to VSD

Additional Detail:

Code Sections

IECC	ASHRAE
2009: 503.4.4	2007: 6.5.5.2
2012: 403.4.4	2010: 6.5.5.2

Multi-zone Systems

Large buildings typically have HVAC systems that can heat, cool, reheat, and recool air moving to multiple zones at the same time. Multiple-zone systems must have VAV controls capable of reducing the supply air to any zone before reheating, recooling, or mixing warm and cool air streams. IECC 2012 requires the supply air to be reduced to 30% of maximum, to 300 CFM, or to the level required for minimum ventilation before any reheating, recooling or mixing. The requirements of ASHRAE are similar, though systems shown to reduce annual energy use by providing more supply air are allowed. ASHRAE 2010 also introduces a method for systems with digital control of zone boxes to control the outdoor air intake based on the "zone ventilation efficiency" — the efficiency at which the system delivers outside air to the breathing zone.

Plan Review

Suggested Compliance Check(s):

- Verify that control sequences include language for VAV system optimization (i.e. indicate that supply air is reduced prior to reheating/recooling):
    - Single duct VAV systems should reduce supply air before reheating/recooling takes place

    - Dual duct VAV systems should minimize the amount of hot/cold air mixing by reducing flow (figure 37)

- Verify that language for supply air temperature reset is included in control sequences (figure 38)

Figure 37: Sample control sequence for dual duct VAV system

Occupied Mode

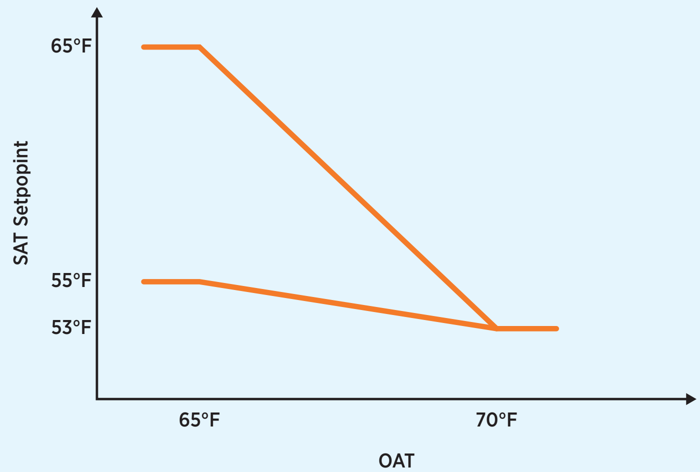
- Cooling
    - Full cooling: Cold deck air damper opens to the maximum position.
    - As cooling load decreases, cold deck air damper modulates more closed.
    - No call for cooling: Cold deck air damper closes to the minimum position.
- Heating
    - Full heating: Hot deck air damper opens to the maximum position.
    - As heating load decreases, hot deck air damper modulates more closed.
    - No call for heating: Hot deck air damper closes to the minimum position.

Figure 38: Sample control sequence for supply air temperature reset

Supply Air Temperature Reset

When occupied, the supply air temperature (SAT) is reset from 53°F to 65°F using the following logic:

- When the outside air temperature (OAT) is 70°F and above, SAT shall be 53°F.
- When OAT is 65°F to 70°F, the SAT is reset based on system demand between minimum and maximum values that vary linearly with temperature (see figure).
- When OAT is below 65°F, reset SAT between 55°F and 65°F based on system demand.
- System demand is determined using a trim and respond logic:
    - When the fan is off, SAT is at 65°F
    - When the fan is on, every 2 minutes:
        - Increase the SAT setpoint by 0.2°F if there are no zone cooling requests*
        - If there are more than two cooling requests, decrease the setpoint by 0.3°F



* cooling requests are generated when the cooling loop of any zone served is >99%

Source: EnergyDesignResources, Advanced Variable Air Volume System Design Guide, March 2007

Building Inspection

Suggested Compliance Check(s):

- Confirm that the building automation system specified in the approved design is installed and operational.
- Checking that multi-zone VAV systems are optimized is an intensive procedure, well beyond the scope of building inspection. However, ASHRAE 90.1-2010 and IECC 2012 require commissioning to be performed on many commercial buildings. The commissioning provider’s report should describe how the system was tested and optimized.

Additional Details:

a) Multi zone VAV system optimization control

Systems with digital control of zone boxes must automatically adjust supply air in response to changes in system ventilation efficiency. This approach allows outside air supply to be provided at below design rates, so long as the zone that is least effective in delivering outside air to the breathing zone maintains acceptable indoor air quality. Detailed guidance on this approach is provided in ASHRAE Standard 62.1.

Code Sections

IECC	ASHRAE
2009: NA	2007: NA
2012: NA	2010: 6.5.3.3

b) Single duct VAV systems

Terminal Units shall reduce supply of supply air to 30% of maximum, to 300 CFM, or to a level sufficient to provide the minimum required ventilation before reheating/recooling.

Code Sections

IECC	ASHRAE
2009: 503.4.5.1	2007: - 6.5.2.1
2012: 403.4.5.1	2010: 6.5.2.1

c) Dual duct VAV systems

Dual duct systems shall have terminal units that can minimize flow from one duct to 30% of maximum, to 300 CFM, or to a level sufficient to provide the minimum required ventilation prior to mixing from second duct.

Code Sections

IECC	ASHRAE
2009: 503.4.5.2	2007: 6.5.2,1
2012: 403.4.5.2	2010: 6.5.2.1

d) Supply air temperature reset

Supply air temperature (SAT) reset is required for multi zone HVAC systems. SAT must be reset in response to building load or outside air temperature. The controls must allow SAT reset that is at least 25 percent of the difference between the design SAT and room air temperature.

Code Sections

IECC	ASHRAE
2009: 503.4.5.4	2007: NA
2012: 403.4.5.4	2010: 6.5.3.4

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