

Sequences of Operation from *Practical Controls: A Guide to Mechanical Systems*

Exhaust Fan

Fume hood exhaust fan EF-1 is manually operated by a user switch, located in the space being served by the fan.

Hot Water System

Hot water system to be in operation whenever the outside air temperature is below 60 degrees F. (adj.). System enable/disable to be performed automatically, by an outside air temperature controller. When enabled, the pump selected as the "primary" pump is to run continuously. Selection of the primary pump is a manual procedure, performed by a primary pump selector switch. Upon failure of the primary pump, the backup pump is to automatically start. Boilers are to operate, via a common temperature controller, to maintain hot water temperature setpoint. Setpoint is to be a function of outside air temperature. As the outside air temperature increases, the hot water temperature setpoint is "reset" downwards. Miscellaneous unitary hot water heating equipment throughout the building is to operate via integral controls, to maintain desired comfort levels.

Refrigeration Cycle

The refrigeration cycle consists minimally of a compressor, a condenser, an expansion device, and an evaporator. The compressor is the heart of the system, and is used to pump low-pressure refrigerant vapor from the evaporator and compress it to a higher pressure. This hot, high-pressure vapor is delivered to the condenser, where it rejects its heat to the ambient (outside) air. As the heat is removed from the refrigerant, it condenses, and turns to a high-temperature liquid. The refrigerant, now in its liquid phase, passes through an expansion device that substantially reduces the pressure and temperature of the liquid refrigerant. The cool, low-pressure liquid refrigerant is then delivered to the evaporator. In this application, the evaporator is a finned coil of which the rooftop unit's supply air passes over. As the air passes over the evaporator, it's cooled down. The refrigerant absorbs the heat from the air, and boils. The refrigerant, now a vapor again, is drawn to the compressor, and the cycle continues...

Economizer

The outside air enthalpy or dry bulb sensor monitors outside air conditions. If outside air conditions are suitable for "free cooling" as determined by the sensor and the economizer controller "enable" setting, then economizer operation is allowed.

Upon a call for "first stage cooling", economizer operation is initiated. Outside and return air dampers begin to modulate (from minimum position) in order to maintain a suitable discharge air temperature (typically between 50 and 56 degrees). If necessary, the outside air damper will modulate fully open in an effort to achieve this temperature, though depending upon the outside air temperature (and the economizer controller "enable" setting) may not be able to. In other words, if the economizer controller is set to allow economizer operation at a "higher" outside air enthalpy or dry bulb temperature, then the temperature of the outside air may be higher than what is trying to be maintained at the discharge, and therefore the outside air damper will modulate fully open without succeeding to achieve this discharge air temperature setpoint. Depending upon the cooling requirements, this may or may not be sufficient to satisfy the call for "first stage cooling".

If economizer operation alone is not sufficient to satisfy the requirement for cooling, resulting in a call for "second stage cooling", then "first stage DX cooling" is engaged. The DX coil becomes active, and the outside and return air dampers continue to modulate to maintain a suitable discharge air temperature as sensed by the discharge air sensor, which is located downstream of the coil. With the DX coil active, the resulting action of the economizer dampers is that they modulate back down toward minimum position in order to continue to maintain the discharge air temperature setpoint (as sensed downstream of the DX coil).

As the requirement for cooling is satisfied, then DX cooling and economizer operation are disengaged in the reverse order that they were engaged.

Single Zone Rooftop Unit

A programmable thermostat controls the operation of the rooftop unit. Desired occupied and unoccupied heating and cooling setpoints are programmed via the thermostat. Fan operation is determined by the position of the fan "ON-AUTO" switch, as well as by the mode of occupancy. Heating and cooling operation as described herein assumes that the system "HEAT-AUTO-COOL-OFF" switch is in the "AUTO" position.

Occupied Mode

Programmable thermostat signifies occupied mode. Supply fan either runs continuously, or cycles upon a call for heating or cooling, as determined by the position of the fan switch. Outside air damper opens to its minimum position (20 percent adj.) when the supply fan is in operation.

Upon a rise in space temperature above the occupied cooling setpoint, rooftop unit cooling is initiated:

If the outside air is not suitable for free cooling as determined by the outside air dry bulb temperature (or enthalpy) controller, then outside air damper remains at minimum position, and first stage DX cooling is engaged. Upon a further rise in temperature above the occupied cooling setpoint, then second stage DX cooling is engaged (if the rooftop unit is equipped with two compressors). As the space temperature falls back toward setpoint, then the cooling stages are disengaged in the reverse order that they were engaged.

If the outside air is suitable for free cooling as determined by the outside air dry bulb temperature (or enthalpy) controller, then outside and return air dampers modulate to maintain a suitable discharge air temperature (typically 55 degrees). If the outside air damper modulates fully open and economizer operation cannot satisfy the cooling needs of the space, resulting in a call for second stage cooling by the programmable thermostat, then first stage DX cooling is engaged as well. As the space temperature falls back toward setpoint, then DX cooling and economizer operation are disengaged in the reverse order that they were engaged.

Upon a drop in space temperature below the occupied heating setpoint, rooftop unit heating is initiated:

Outside air damper remains at minimum position, and first stage gas-fired heating is engaged. Upon a further drop in temperature below the occupied heating setpoint, then second stage gas-fired heating is engaged (if the rooftop unit is equipped with a two-stage gas valve). As the space temperature rises back toward setpoint, then the heating stages are disengaged in the reverse order that they were engaged.

Unoccupied Mode

Programmable thermostat signifies unoccupied mode. Supply fan cycles upon a call for heating or cooling. Outside air damper opens to minimum position upon a call for heating or cooling. Unoccupied heating setpoint is lower than occupied heating setpoint (60 degrees adj.). Unoccupied cooling setpoint is higher than occupied setpoint (80 degrees adj.). Rooftop unit heating and cooling operate as described above in Occupied Mode, except as to maintain unoccupied heating and cooling setpoints.

Built Up Air Handling Units

Constant Volume, Single Zone System

During occupied modes, the air handling unit operates to maintain the occupied mode comfort level of the space served. The fans run continuously (at a constant rate), and the outside air damper is open to its minimum position. If the space temperature falls from heating setpoint, then the hot water valve is modulated open. If the outside air is not suitable for free cooling and the space temperature rises from cooling setpoint, then the chilled water valve is modulated open. If the outside air is suitable for free cooling, then the outside air damper is modulated open as the first means of cooling (economizer operation). If space cooling demand is such that economizer operation alone cannot satisfy the needs of the space, then the chilled water valve is modulated open as well.

During unoccupied modes, the air handling unit operates (as required) to maintain the space temperature between unoccupied heating and cooling setpoints (typically 60 and 80 degrees, respectively). If the space

temperature strays out of this range, then the fans turn on, and the unit heats or cools as necessary in order to bring the space temperature back into the range defined by the unoccupied mode setpoints. Outside air damper remains closed during unoccupied mode operation.

Constant Volume Reheat System

During occupied modes, the air handling unit operates to maintain a constant discharge air temperature (typically 55 degrees). The fans run continuously (at a constant rate), and the outside air damper is open to its minimum position. If the outside air is not suitable for free cooling, then the chilled water valve is modulated to maintain discharge air temperature setpoint. If the outside air is suitable for free cooling, then the outside air damper is modulated open as the first means of cooling (economizer operation). If discharge air temperature setpoint cannot be attained by economizer operation alone, then the chilled water valve is modulated open as well. Hot water valve is modulated open to "heat" to discharge air temperature setpoint, if conditions are such that an extensive amount of cold outside air is being brought in via the outside air damper. Otherwise, hot water valve is closed during occupied modes. Reheat coils perform individual zone comfort control, by receiving cool air and reheating it as necessary in order to maintain zone setpoints.

During unoccupied modes, the air handling unit operates (as required) to maintain the space temperature between unoccupied heating and cooling setpoints (typically 60 and 80 degrees, respectively). If the temperature of the general space served by the air handling unit strays out of this range, then the fans turn on, and the unit heats or cools as necessary in order to bring the space temperature back into the range defined by the unoccupied mode setpoints. Outside air damper remains closed during unoccupied mode operation.

A morning warmup cycle may be implemented, upon transition from unoccupied to occupied mode. Fans turn on, outside air damper remains closed, and hot water valve is driven fully open. Unit remains in this mode until the space or return air temperature reaches the morning warmup cycle termination setpoint. Upon reaching this setpoint, the air handling unit enters its normal occupied mode of operation (discharge air temperature control).

Variable Air Volume (VAV) System

During occupied modes, the air handling unit operates to maintain a constant discharge air temperature (typically 55 degrees). The fans run continuously (at a variable rate), and the outside air damper is open to its minimum position. Supply fan operates to maintain a suitable duct static pressure, and exhaust/return fan operates to maintain a suitable space static pressure. If the outside air is not suitable for free cooling, then the chilled water valve is modulated to maintain discharge air temperature setpoint. If the outside air is suitable for free cooling, then the outside air damper is modulated open as the first means of cooling (economizer operation). If discharge air temperature setpoint cannot be attained by economizer operation alone, then the chilled water valve is modulated open as well. Hot water valve is modulated open to "heat" to discharge air temperature setpoint, if conditions are such that an extensive amount of cold outside air is being brought in via the outside air damper. Otherwise, hot water valve is closed during occupied modes. VAV boxes perform individual zone comfort control, by receiving cool air, and varying the rate at which it is delivered into the zones in order to maintain zone setpoints. Zone level reheat may apply as well.

During unoccupied modes, the air handling unit operates (as required) to maintain the space temperature between unoccupied heating and cooling setpoints (typically 60 and 80 degrees, respectively). If the temperature in the general space served by the air handling unit strays out of this range, then the fans turn on, and the unit heats or cools as necessary in order to bring the space temperature back into the range defined by the unoccupied mode setpoints. Outside air damper remains closed during unoccupied mode operation.

A morning warmup cycle may be implemented, upon transition from unoccupied to occupied mode. Fans turn on, outside air damper remains closed, and hot water valve is driven fully open. Unit remains in this mode until the space or return air temperature reaches the morning warmup mode termination setpoint. Upon reaching this setpoint, the air handling unit enters its normal occupied mode of operation (discharge air temperature control).

VVT System

Overall System Control

Rooftop unit mode (heating, cooling, or ventilation) is determined by the needs of the individual zones. For instance, if more zones are in need of cooling rather than heating, then the rooftop unit will operate in a cooling mode. Conversely, if more zones are in need of heating rather than cooling, then the rooftop unit will operate in a heating mode.

If there is no heating or cooling demand by any of the zones, then rooftop unit heating and cooling are disengaged, and the supply fan continues to run (ventilation mode).

Individual Zone Control

Once the mode of operation is established, then the zone dampers for those zones that are in need of the current mode (cooling or heating) will “modulate”, or periodically adjust position, in order to maintain the desired zone temperature setpoints.

The zone dampers for those zones that aren't in need of the current mode will drive fully closed or to their minimum positions.

As setpoints are reached and consequently zone dampers close off, the system bypass damper will modulate open in order to maintain airflow through the rooftop unit, and also to prevent excessive pressure buildup in the ductwork.

FP Box in Unoccupied Mode

During the occupied modes, the (series or parallel) fan powered box operates in the manner that is typical for the type of box. When the air handler shuts down for the night, the fan powered box goes into a “setback” mode. Its fan shuts down, and the primary air damper closes completely. If the temperature of the zone served by the fan powered box drops below the setback setpoint of 62 degrees, then the fan energizes and the heating coil is engaged, to pull air from the plenum, heat it up, and dump it into the space. Once the space temperature rises back above this setback setpoint, the fan and heat are disengaged. If the main air handler comes on for a general night setback cycle, the box will know of this, and simply think that the air handler has entered the occupied mode. The primary air damper will be enabled, and will likely go to minimum position. The fan and heat will operate via occupied setpoint, and likely go to full capacity. The air delivered into the zone during an air handler night setback cycle will be a mixture of minimal (warm) primary air and plenum air, heated by the heating coil. Once the main air handler's night setback cycle is satisfied, and the air handler shuts down, the box reverts back to its setback mode. Upon morning warmup cycle, the box behaves in the same way as it does for a night setback cycle. Once morning warmup is terminated, and the air handler enters its normal occupied mode of operation, the fan powered box returns to its normal mode of operation as well.

VAV & Fan Powered Boxes

Cooling Only VAV Boxes

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the VAV box controller. The controller in turn modulates the primary air damper in order to deliver the appropriate amount of cool air from the medium pressure duct into the zone. As the zone temperature falls toward setpoint, the damper is modulated closed toward its minimum position. When the zone temperature reaches setpoint, the damper reaches its minimum position.

Unoccupied and Morning Warmup Modes

The primary air damper is driven fully open during the unoccupied mode, to allow for main air handler night setback and morning warmup heating cycles.

VAV Boxes with Electric Reheat

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the VAV box controller. The controller in turn modulates the primary air damper in order to deliver the appropriate amount of cool air from the medium pressure duct into the zone. As the zone temperature falls toward setpoint, the damper is modulated closed toward its minimum position. When the zone temperature reaches setpoint, the damper reaches its minimum position. If the temperature in the zone continues to fall, then the primary air damper opens to an intermediate "heating" position, and electric heat is staged. The further the temperature falls from zone setpoint, the more stages of heat are engaged.

Unoccupied and Morning Warmup Modes

The primary air damper is driven fully open during the unoccupied mode, to allow for main air handler night setback and morning warmup heating cycles. VAV box electric heat is disabled.

VAV Boxes with Hot Water Reheat

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the VAV box controller. The controller in turn modulates the primary air damper in order to deliver the appropriate amount of cool air from the medium pressure duct into the zone. As the zone temperature falls toward setpoint, the damper is modulated closed toward its minimum position. When the zone temperature reaches setpoint, the damper reaches its minimum position. If the temperature in the zone continues to fall, then the primary air damper opens to an intermediate "heating" position, hot water heat is engaged, and the hot water valve is modulated. The further the temperature falls from zone setpoint, the more hot water is allowed to flow through the coil.

Unoccupied and Morning Warmup Modes

The primary air damper is driven fully open during the unoccupied mode, to allow for main air handler night setback and morning warmup heating cycles. VAV box hot water heat is disabled.

Series Fan Powered Boxes with Heat

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the fan powered box controller. The controller in turn modulates the primary air damper in order to allow the appropriate amount of cool air from the medium pressure duct into the box. The air is then blended with warm air circulated from the plenum by the fan, which is in continuous operation during the occupied mode. The resulting air delivered into the zone is of constant volume (as dictated by fan speed) and variable temperature. As the zone temperature falls toward setpoint, the damper is modulated closed toward its minimum position, allowing less and less cool air to be blended with the plenum air. When the zone temperature reaches setpoint, the damper reaches its minimum position. If the temperature in the zone continues to fall, then terminal unit [electric / hot water] heat is engaged. The further the temperature falls from zone setpoint, the more heat is engaged.

Unoccupied and Morning Warmup Modes

The primary air damper is driven [fully open / fully closed] during main air handling unit shutdown modes. The fan and heat cycle to maintain a reduced zone temperature setpoint. During air handler night setback and morning warmup heating cycles, the primary air damper assumes its [fully open / minimum] position, the fan runs, and terminal unit heat is controlled to occupied mode zone setpoint.

Parallel Fan Powered Boxes with Heat

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the fan powered box controller. The controller in turn modulates the primary air damper in order to deliver the appropriate amount of cool air from the medium pressure duct into the zone. The air delivered into the zone is

of variable volume and constant temperature. As the zone temperature falls toward setpoint, the damper is modulated closed toward its minimum position. When the zone temperature reaches setpoint, the damper reaches its minimum position. If the temperature in the zone falls below setpoint, the fan energizes to circulate warm air from the plenum. The plenum air is blended with the minimal cool air from the primary air damper, and delivered to the zone. If the temperature in the zone continues to fall, then terminal unit [electric / hot water] heat is engaged. The further the temperature falls from zone setpoint, the more heat is engaged.

Unoccupied and Morning Warmup Modes

The primary air damper is driven [fully open / fully closed] during main air handling unit shutdown modes. The fan and heat cycle to maintain a reduced zone temperature setpoint. During air handler night setback and morning warmup heating cycles, the primary air damper assumes its [fully open / minimum] position, and terminal unit fan and heat are controlled to occupied mode zone setpoint.

Constant Volume Terminal Units with Reheat

Occupied Mode

An individual zone sensor (one per zone/box) transmits zone temperature and zone setpoint information to the terminal unit controller. The controller modulates the primary air damper in order to deliver a constant amount of air from the medium pressure duct into the zone, independent of the temperature needs of the zone. If the temperature in the zone falls below setpoint, then terminal unit [electric / hot water] heat is engaged. The further the temperature falls from zone setpoint, the more heat is engaged.

Unoccupied and Morning Warmup Modes

The primary air damper is driven fully open during the unoccupied mode, to allow for main air handler night setback and morning warmup heating cycles. Terminal unit heat is disabled.

Pump Sequencer

Normal Operation

- 1) Control input (external call for pumping operation) closes, signaling the panel to start the primary pump.
- 2) Primary pump, as selected by a scheduling function, starts and runs continuously. Primary pump alternation occurs weekly.
- 3) Green indicator light respective to this pump is lit.
- 4) After a short time, differential pressure switch installed across the common suction and discharge of both pumps makes, thus proving pump operation. Built-in time delay allows for enough time for this switch to make, once a command for pumping has been issued, before transferring to "failure mode".
- 5) Primary pump continues to run until the control input opens, or until the scheduling function selects the other pump to be the primary pump.

Failure Mode

- 1) External command for pumping exists, and primary pump is running continuously.
- 2) Primary pump fails. Differential pressure switch breaks, indicating a failure.
- 3) After a short time delay, system enters "failure mode":
 - Primary pump is electrically disabled.
 - Backup pump automatically starts.
 - Green indicator light respective to this pump is lit.
 - Red failure light is lit.
- 4) For as long as the system is in this mode, the backup pump will run whenever the control input is closed.
- 5) The failure indicator light will remain lit for as long as the system is in this mode.
- 6) At this point, the failed pump should be checked out and repaired as necessary. Once this pump has been repaired, the reset pushbutton can be pressed to restore the system to normal operation.