Appendix G
CONTROLS

This appendix describes representative sequences of control operations for a variety of HVAC systems. The symbols used in the figures and the underlying control philosophies for these systems are given in Chapter 10.

The purpose of this appendix is to suggest the logic inherent in control sequences—not to define sequences for all possible systems and equipment. Electric-pneumatic interfaces are often noted below—these general descriptions (less the E-P interface) are equally applicable to all-electric/electronic controls (including DDC).

G.1 VAV SYSTEM, FAN SPEED CONTROL, RADIATION HEATING, NO RETURN FAN—SEQUENCE OF OPERATIONS

Refer to Figures G-1 and G-2.

A. Start-up

1. The supply fan may be started and stopped in one of two ways:

Manually. The "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF' position to stop the fan.

Automatically. With the fan motor starter switch in the "AUTO" position, the VAV system has three modes of operation—off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1. (In many applications, a central building automation system (BAS) may be used.) This contact closure provides power to the fan motor starter. Power to the hot water temperature control panel, VAV temperature control panel, and static pressure control panel is supplied through auxiliary contacts M1-l, M1-2, and M1-3 on the supply fan motor starter.

3. At the end of the occupied period, the time clock switch TC1 (or a BAS) deenergizes the fan starter relay, consequently interrupting power to all the control panels.

Fig. G-1 VAV Fan Speed Control (FSC) System.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostats (T7) are located as shown in the drawings. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the hot water temperature control panel and, through an electric-to-pneumatic switch (not shown),

pressure is supplied to the zone thermostats. Auxiliary contact R1-2 (normally closed) opens, and the VAV temperature control panel remains deenergized. Through auxiliary contact R1-3, the fan motor starter is energized, and power is supplied to the static pressure control panel (through auxiliary contact M1-3). With no power to the VAV temperature control panel, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heating element in the zone controlled by the zone thermostat. With the fan on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

Fig. G-2 Control Circuit for System shown in Figure G-1.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2 (or contacts remotely controlled by a BAS) are energized for a period before occupancy. Closure of these contacts has the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. Static Pressure Control

1. The static pressure at a representative point in the ductwork is held constant by the static pressure control panel.

2. A tube connects a static pressure tap in the ductwork to static pressure sensor DP1 located in the static pressure control panel. The electronic output of the pressure sensor is compared to the static pressure setpoint in electronic PI controller C3. The electronic output of controller C3 is connected to fan motor speed controller FSC on the supply fan.

3. The panel is equipped with a soft start circuit. When power is supplied to the static pressure control panel through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 s occurs while the output of controller C3 is ramped to zero. During this delay, the output of controller C3 is disconnected from controller FSC. After the delay, the output from controller C3 is reconnected to controller FSC, allowing the supply fan to run. The setpoint is gradually ramped from zero up to the desired setpoint (as determined by the setpoint adjustment knob), after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features, which, by turning the timer and pressing the "SET" button, allow the output of the panel to be adjusted by turning the manual adjust knob. When the panel is switched to the manual mode, the soft start circuit first disconnects the input to controller FSC. After a delay of about 15 s, the input to controller FSC is reconnected, and the voltage output to controller FSC is ramped from zero to the desired voltage as determined by the position of the manual adjust knob. Once the manual adjustment voltage is reached, any manual output changes (i.e., manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drive from

tripping its circuit breakers. The system is returned to automatic control when the timer runs down or when the reset button is pushed. When this occurs, the soft start circuit functions as if the fan were just being started. The timer or reset button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the reset button.

C. Supply and Mixed-Air Temperature Control

1. The supply air temperature is controlled by electronic PI controller C1, located in the VAV temperature control panel.

2. The mixed-air temperature is controlled by electronic PI controller C2, located in the VAV temperature control panel.

3. The cooling coil chilled-water valve V1 is modulated by controller C1 using the sensed supply air temperature from temperature sensor T1. The output from controller C1 is connected to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The setpoint of controller C1 is 60°F [15.6°C].

4. The outdoor, relief, and return air dampers are modulated by controller C2 using the sensed mixed-air temperature from temperature sensor T2. The output from controller C2 is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When using more than minimum outdoor air is economical, the signal from controller C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly. The setpoint of controller C2 is 60°F [15.6°C] minus the temperature rise across the fan (under full airflow conditions).

5. BAS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open and 1 and 2 shorted, the economizer works as described above. With all contacts shorted, the comparator is bypassed, and the control signal is sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysteresis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0°F [1.1°C] below the return air temperature before the relay closes; if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels), the outdoor air dampers return to their normally closed position.

D. Zone Air Temperature Control

1. Zone air temperature control is achieved by zone temperature sensors sending a signal to an application specific controller (ASC) to modulate individual VAV boxes. When heating is required, the room temperature sensor also modulates baseboard heater valve V2.

2. Thermostat calibration and selection of actuator ranges shall be coordinated to provide the control action shown in Figures 10-7 and 10-8 (Chapter 10)—not necessary with DDC.

E. Hot Water Temperature Control

The temperature of hot water supplied to the baseboard heaters is controlled by the hot water temperature control panel.

F. Interlocks

Smoke detectors (SD1 and SD2), the low-temperature safety switch (FZ), and the high-pressure limit switch (HP1) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

G.2 VAV SYSTEM, FAN SPEED CONTROL, REHEAT, NO RETURN FAN—SEQUENCE OF OPERATIONS

Refer to Figures G-1 and G-2.

The sequence of operations is identical to that described in Section G-1, with the following exceptions:

1. The last three sentences under Section A.4 are replaced with the following:

"Heat is provided through a reheat coil in the zone duct controlled by the room thermostat. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state."

2. In Section D, line 3, the words "baseboard heater" are replaced with the words "reheat coil."

3. In Section E, line 1, the words "baseboard heaters" are replaced with the words "reheat coils."

G.3 VAV SYSTEM, FAN SPEED CONTROL, RADIATION HEATING, RETURN FAN—SEQUENCE OF OPERATIONS

Refer to Figures G-3 and G 4.

A. Start-up

1. The supply fan and return fan may be started and stopped in one of two ways:

Manually. The "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

Automatically. With the fan motor starter switch in the "AUTO" position, the VAV system has three modes of operation—off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1 (or, in many applications, a central building automation system (BAS)). This contact closure provides power to the fan motor starters, M1 and M2, and relay R2. Power to the hot water temperature control panel, the VAV temperature control panel, and the static pressure control panel is supplied through auxiliary contacts R2-1, R2-2, and R2-3.

3. At the end of the occupied period, time clock switch TC1 (or a BAS) deenergizes the fan starter relays, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Figures G-3 and G-4. If the temperature drops below the setpoint of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact Rl-l, power is supplied to the hot water temperature control panel and, through an electric-to-pneumatic switch (not shown), pressure is supplied to the zone thermostats. Auxiliary contact R1-2 (normally closed) opens, and the VAV temperature control panel remains deenergized. Through auxiliary contacts R1-3 and R1-4, the fan motor starters are energized, and power is supplied to the static pressure control panel (through auxiliary contact R2-3). With no power to the VAV temperature control panel, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heating element in the zone controlled by the zone thermostat. With the fan on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2 (or contacts remotely controlled by a BAS) is energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of

contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. Static Pressure Control

1. The static pressure at a representative point in the ductwork is held constant by the static pressure control panel.

2. A tube connects a static pressure tap in the ductwork to static pressure sensor DP1 1ocated in the static pressure control panel. The electronic output of the pressure sensor is compared to the static pressure setpoint in electronic PI controller C3. The electronic output of controller C3 is connected to fan motor speed controller FSC on the supply fan.

3. The panel is equipped with a soft start circuit. When power is supplied to the static pressure control panel through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 s occurs while the output of controller C3 is ramped to zero. During this delay, the output of controller C3 is disconnected from controller FSC. After the delay, the output from controller C3 is reconnected to controller FSC, allowing the supply fan to run. The setpoint is gradually ramped from zero up to the desired setpoint (as determined by the setpoint adjustment knob), after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features, which, by turning the timer and pressing the "SET" button, allow the output of the panel to be adjusted by turning the manual adjust knob. When the panel is switched to the manual mode, the soft start circuit first disconnects the input to controller FSC. After a delay of about 15 s, the input to controller FSC is reconnected, and the voltage output to controller FSC is ramped from zero to the desired voltage as determined by the position of the manual adjust knob. Once the manual adjustment voltage is reached, any manual output changes (i.e., manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drive from tripping the circuit breakers. The system is returned to automatic control when the timer runs down or when the reset button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or reset button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the reset button.

Fig. G-3 VAV Fan Speed Control (FSC) System with Return Fan.

Fig G-4 Control Circuit for System shown in Figure G-3.

C. Supply and Mixed-Air Temperature Control

1. The supply air temperature is controlled by electronic PI controller C1, located in the VAV temperature control panel.

2. The mixed-air temperature is controlled by electronic PI controller C2 located in the VAV temperature control panel.

3. The cooling coil chilled-water valve V1 is modulated by controller C1 using the sensed supply air temperature from temperature sensor T1. The output from controller C1 is connected to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The setpoint of controller C1 is 60°F [15.6°C].

4. The outdoor, relief, and return air dampers are modulated by controller C2 using the sensed mixed-air temperature from temperature sensor T2. The output from controller C2 is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from controller C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly. The setpoint of controller C2 is 60°F [15.6°C] minus the temperature rise across the fan (under full airflow conditions).

5. BAS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open and 1 and 2 shorted, the economizer works as described above. With all contacts shorted, the comparator is bypassed, and the control signal is sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysteresis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0°F [1.1°C] below the return air temperature before the relay closes; if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels), the outdoor air dampers return to their normally closed position.

D. Room Air Temperature Control

1. Room air temperature control is achieved by room thermostats modulating individual VAV boxes. When heating is required, the zone thermostat also modulates baseboard heater valve V2.

2. Thermostat calibration and selection of actuator ranges shall be coordinated to provide the control action shown in Figures 10-7 and 10-8 (Chapter 10)—not necessary with DDC.

E. Hot Water Temperature Control

The temperature of hot water supplied to the baseboard heaters is controlled by the hot water temperature control panel.

F. Interlocks

Smoke detectors (SD1 and SD2), the low-temperature safety switch (FZ), and the high-pressure limit switches (HP1 and HP2) are wired in series with the fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic in Figures G-3 and G-4 shows how equipment is to be interlocked.

G.4 VAV SYSTEM, FAN SPEED CONTROL, REHEAT, RETURN FAN—SEQUENCE OF OPERATIONS

Refer to Figures G-3 and G 4.

The sequence of operations is identical to that described in Section G-l, with the following exceptions:

1. The last three sentences under Section A.4 are replaced with the following:

"Heat is provided through a reheat coil in the zone duct controlled by the zone thermostat. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state."

2. In Section D, line 3, the words "baseboard heater" are replaced with the words "reheat coil."

3. In Section E, line l, the words "baseboard heaters" are replaced with the words "reheat coils."

G.5 VAV SYSTEM, FAN INLET GUIDE VANE CONTROL—SEQUENCE OF OPERATIONS

Refer to Figures G-5 and G-6.

The sequence of operations is identical to that described in Sections G-l through G-4, except that fan speed control is replaced by control of the inlet guide vanes (see Figures G-5 and G-6). Replace the words "controller FSC" with the words "E/P-3" in Sections G-l through G-4.

Fig. G-5 VAV Inlet Guide Vane (IGV) Control System.

Fig. G-6 Control Circuit for System shown in Figure G-5.

G.6 SMALL SINGLE-ZONE SYSTEM, ONE CONTROLLER—SEQUENCE OF OPERATIONS

Refer to Figure G-7.

A. Start-up

1. The supply fan ~~and return fan~~ may be started and stopped in one of two ways:

Manually. The "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF' position to stop the fan.

Automatically. With the fan motor starter switch in the "AUTO" position, the single-zone HVAC system has three modes of operation—off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1 (or, perhaps, a central building automation system (BAS)). This contact closure provides power to the fan motor starter. Power to the single-zone temperature control panel and the hot water temperature control panel is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1 (or a BAS) deenergizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T3) are located as shown in the drawings. If the temperature drops below the setpoint of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact Rl-l, power is supplied to the fan motor starter, and the single-zone temperature control panel and the hot water temperature control panel are energized (through auxiliary contacts M1-1 and M1-2). Auxiliary contact R1-2 (normally closed) opens and deenergizes electrically actuated pneumatic switch EPS 1, returning it to its normal position. Thus EPS 1 disconnects the damper actuators from their pneumatic control signal and allows the dampers to return to their normal states, preventing outdoor air from entering the system. Heat is provided through heating coil valve V1, which is regulated by controller C 1. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2 (or contacts remotely controlled by a BAS) is energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of

contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. Supply and Mixed-Air Temperature Control

1. The mixed-air temperature and the supply air temperature are controlled by electronic proportional controller C1, located in the single-zone temperature control panel.

2. The heating coil hot water valve V1 and the cooling coil chilled water valve V2 are modulated by controller C1 using the sensed air temperature from temperature sensor T1. The output from controller C1 is connected to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to position valves V1 and V2 accordingly, maintaining a constant supply air temperature. The setpoint of controller C1 is the desired room temperature (72 to 74°F [22.2 to 23.3°C]).

Fig. G-7 Single-Zone System with Simple Control.

3. The outdoor, relief, and return air dampers are also modulated by controller C1 using the sensed air temperature from temperature sensor T1. The output from controller C1 is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from controller C1 will be higher than the signal from SW1, and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly.

4. BAS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open and 1 and 2 shorted, the economizer works as described earlier. With all contacts shorted, the comparator is bypassed, and the control signal is sent directly to the high signal selector. With contacts 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

5. Hysteresis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0°F [1.1°C] below the return air temperature before the relay closes; if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

6. When the system is off (no power to the control panels), the outdoor air dampers return to their normally closed position.

C. Hot Water Temperature Control

The temperature of hot water supplied to the heating coil is controlled by the hot water temperature control panel.

D. Interlocks

Smoke detectors (SD1 and SD2) and the low-temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures. The ladder schematic on the drawings shows how equipment is to be interlocked.

G.7 SINGLE-ZONE SYSTEM, SEPARATE HEATING AND COOLING CONTROLLERS—SEQUENCE OF OPERATIONS

Refer to Figure G-8.

A. Start-up

The start-up procedure is identical to the one described in Section G-6.

B. Mixed-Air Temperature Control

1. The mixed-air temperature is controlled by electronic PI controller C3, located in the single-zone temperature control panel.

2. The outdoor, relief, and return air dampers are modulated by controller C3 using the sensed mixed-air temperature from temperature sensor T3. The output from controller C3 is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-3, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from controller C3 will be higher than the signal from SW1, its value will be passed to E/P-3, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly. The setpoint of controller C3 is determined by the output of electronic proportional controller C4 using the sensed return air temperature from temperature sensor T4—the mixed-air temperature controller is reset on the basis of return air temperature.

3. BAS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open and 1 and 2 shorted, the economizer works as described above. With all contacts shorted, the comparator is bypassed, and the control signal is sent directly to the high signal selector. With contacts 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

4. Hysteresis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0°F [1.1°C] below the return air temperature before the relay closes; if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

5. When the system is off (no power to the control panels), the outdoor air dampers return to their normally closed position.

C. Supply Air Temperature Control

1. The supply air temperature is controlled by the single-zone temperature control panel.

2. The heating coil hot water valve V2 is modulated by electronic PI controller C2 using the sensed air temperature from temperature sensor T2. The output from controller C2 is connected to electronic-to-pneumatic transducer E/P-2, which produces a temperature leaving the heating coil. The setpoint of controller C2 is determined by the output of electronic proportional controller C4 using the sensed return air temperature from temperature sensor T4—the heating coil controller is reset on the basis of return air temperature.

3. The cooling coil chilled-water valve V1 is modulated by electronic PI controller C1 using the sensed supply air temperature from temperature sensor T1. The output from controller C1 is connected to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The setpoint of controller C1 is determined by the output of electronic proportional controller C4 using the sensed return air temperature from temperature sensor T4—the cooling coil controller is reset on the basis of return air temperature.

D. Hot Water Temperature Control

The temperature of hot water supplied to the heating coil is controlled by the hot water temperature control panel.

E. Interlocks

Smoke detectors (SD1 and SD2) and the low-temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures. The ladder schematic in Figure G-8 shows how equipment is to be interlocked.

Fig. G-8 Single-Zone System with Separate Controllers for Heating and Cooling (Cascade Control).

G.8 SINGLE-ZONE SYSTEM WITH HUMIDITY CONTROL—SEQUENCE OF OPERATIONS

Refer to Figure G-9.

The sequence of control operations is the same as in Section G-7, with the following exceptions:

1. Paragraph B-2 is replaced with the following paragraph:

The outdoor, relief, and return air dampers are modulated by controller C1 using the sensed mixed-air temperature from air temperature sensor T1. The output from controller C1 is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When using more than minimum outdoor air is economical, the signal from controller C1 will be higher than the signal from SW1; its value will be passed to E/P-1, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly. The setpoint of controller C1 is 60°F [15.6°C] minus the temperature rise across the fan (under full airflow conditions).

2. Paragraph C is replaced by the following paragraphs:

C. Supply Air Temperature and Humidity Control

1. The supply air temperature and humidity are controlled by the single-zone temperature control panel.

2. The heating coil hot water valve V2 is modulated by electronic PI controller C2 using the sensed return air temperature from temperature sensor T2. The output from controller C2 is connected to electronic-to-pneumatic transducer E/P-2, which produces a pneumatic signal to position valve V2, maintaining a constant supply air temperature. The setpoint of controller C2 is 68°F [20°C].

3. The cooling coil face and bypass dampers are modulated by electronic PI controller C3 using the sensed air temperature from temperature sensor T3. The output from controller C3 is connected to electronic-to-pneumatic transducer E/P-3, which produces a pneumatic signal to position face and bypass dampers accordingly, maintaining a constant supply air temperature. The setpoint of controller C3 is 60°F [15.6°C].

4. The humidifer valve V1 is modulated by electronic proportional controller C4 using the signal from supply air humidity sensor H2. The output of controller C4 goes to electronic-to-pneumatic transducer E/P-4, which produces a pneumatic signal to position valve V1. The setpoint of controller C4 is reset from electronic PI controller C5, which uses the signal from return air humidity sensor H1.

Fig. G-9 Single-Zone System with Humidity Control.

G.9 MULTI-ZONE SYSTEM—SEQUENCE OF OPERATIONS

Refer to Figures G-10 and G-11.

A. Start-up

1. The supply fan and return fan may be started and stopped in one of two ways:

Manually. The "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

Automatically. With the fan motor starter switch in the "AUTO" position, the multi-zone HVAC system has three modes of operation—off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1 (or, in many applications, a central building automation system (BAS)). This contact closure provides power to the fan motor starter. Power to the multi-zone temperature control panel and the hot water temperature control panel is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1 (or a BAS) deenergizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in the drawings. If the temperature drops below the setpoint of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the fan motor starter. Auxiliary contact R1-2 (normally closed) opens, and the multi-zone temperature control panel remains deenergized. Through auxiliary contact M1-2, the hot water temperature control panel is energized and, through an electric-to-pneumatic switch (not shown), pressure is supplied to the zone thermostats. With no power to the multi-zone temperature control panel, the outdoor air dampers and the cooling coil valve remain closed. The heating coil valve remains in its normally open state, and the fan delivers warm air to the zones. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2 (or contacts remotely energized by a BAS) is energized for a period before occupancy. Closure of this contact has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. Mixed-Air Temperature Control

1. The mixed-air temperature is controlled by electronic PI controller C3, located in the multi-zone temperature control panel.

2. The outdoor, relief, and return air dampers are modulated by controller C3 using the sensed mixed-air temperature from temperature sensor T3. The output from controller C3 passes through the "off temperature" relay contact, which disables economizer operation during cold periods. The "off period" relay is connected to the comparator relay, which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic-to-pneumatic transducer E/P-3, which produces a pneumatic signal to hold the outdoor and relief air dampers at their minimum position. When using more than minimum outdoor air is economical, the signal from controller C3 will be higher than the signal from SW1; its value will be passed to E/P-3, which will produce a pneumatic signal to position the outdoor, relief, and return air dampers accordingly. The setpoint of controller C3 is 60°F [15.6°C].

3. BAS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open and 1 and 2 shorted, the economizer works as described earlier. With all contacts shorted, the comparator is bypassed, and the control signal is sent directly to the high signal selector. With contacts 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

4. Hysteresis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0°F [1.1°C] below the return air temperature before the relay closes; if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

Fig. G-10 Multi-Zone System Control.

Fig. G-11 Control Circuit for System shown in Figure G-10.

5. When the system is off (no power to the control panels), the outdoor air dampers return to their normally closed position.

C. Supply Air Temperature Control

1. The supply air temperature is controlled by the multi-zone temperature control panel.

2. The heating coil hot water valve V2 is modulated by electronic PI controller C2 using the sensed hot deck air temperature from temperature sensor T2. The output from controller C2 is connected to electronic-to-pneumatic transducer E/P-2, which produces a

pneumatic signal to position valve V2, maintaining a constant hot deck air temperature. The setpoint of controller C2 is determined by the output of electronic proportional controller C4 using the sensed outdoor air temperature from temperature sensor T4—the heating coil controller is reset on the basis of outdoor air temperature.

3. The cooling coil chilled-water valve V1 is modulated by electronic PI controller C1 using the sensed cold deck air temperature from temperature sensor T1. The output from controller C1 is connected to electronic-to-pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant cold deck air temperature. The setpoint of controller C1 is 58°F [14.4°C].

D. Room Air Temperature Control

Room air temperature control is achieved by pneumatic zone thermostats modulating individual mixing dampers.

E. Hot Water Temperature Control

The temperature of hot water supplied to the heating coil is controlled by the hot water temperature control panel.

F. Interlocks

Smoke detectors (SD1 and SD2) and the low-temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures. The ladder schematic on the drawings shows how equipment is to be interlocked.

Fig. G-1 >>

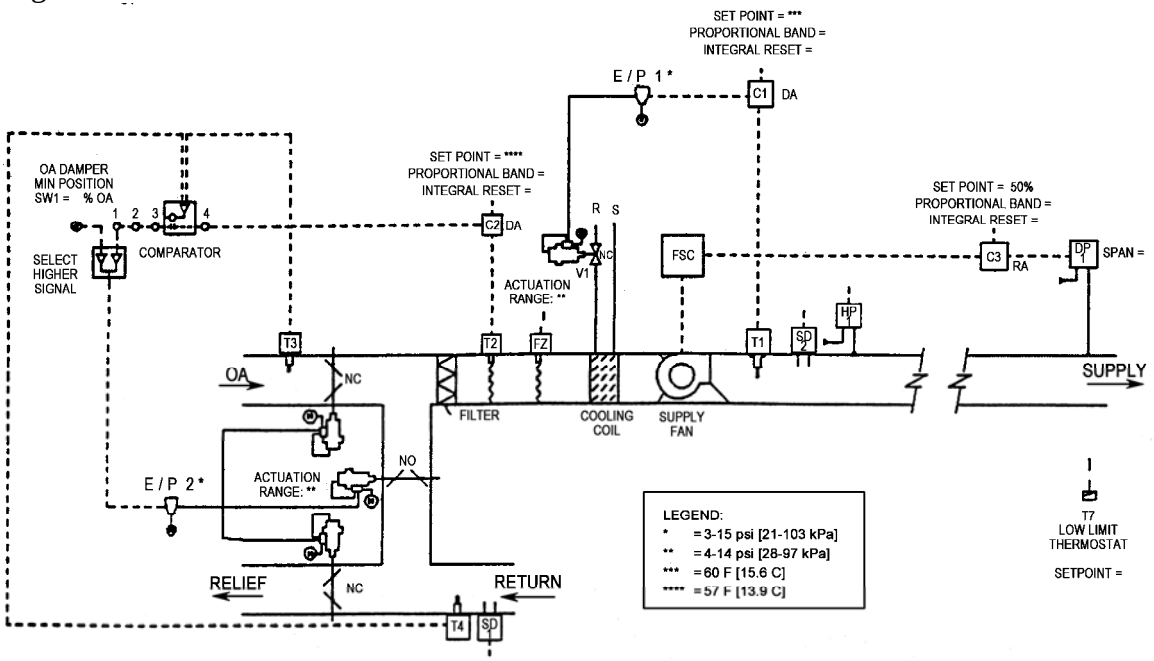

SET POINT = ***
PROPORTIONAL BAND =
INTEGRAL RESET =
E / P 1 *
C1 DA
OA DAMPER
MIN POSITION
SW1 = % OA
1 2 3 4
SELECT
HIGHER
SIGNAL
COMPARATOR
SET POINT = ****
PROPORTIONAL BAND =
INTEGRAL RESET =
C2 DA
R S
V1
ACTUATION
RANGE: **
FSC
SET POINT = 50%
PROPORTIONAL BAND =
INTEGRAL RESET =
C3 RA
DP 1 SPAN =
HP
SD 2
T3
T2
FZ
T1
OA
NC
FILTER
COOLING
COIL
SUPPLY
FAN
SUPPLY
E / P 2 *
ACTUATION
RANGE: **
NO
RELIEF
NC
RETURN
T4
SD 1
T7
LOW LIMIT
THERMOSTAT
SETPOINT =
LEGEND:
* = 3-15 psi [21-103 kPa]
** = 4-14 psi [28-97 kPa]
*** = 60 F [15.6 C]
**** = 57 F [13.9 C]

Fig. G-2 >>

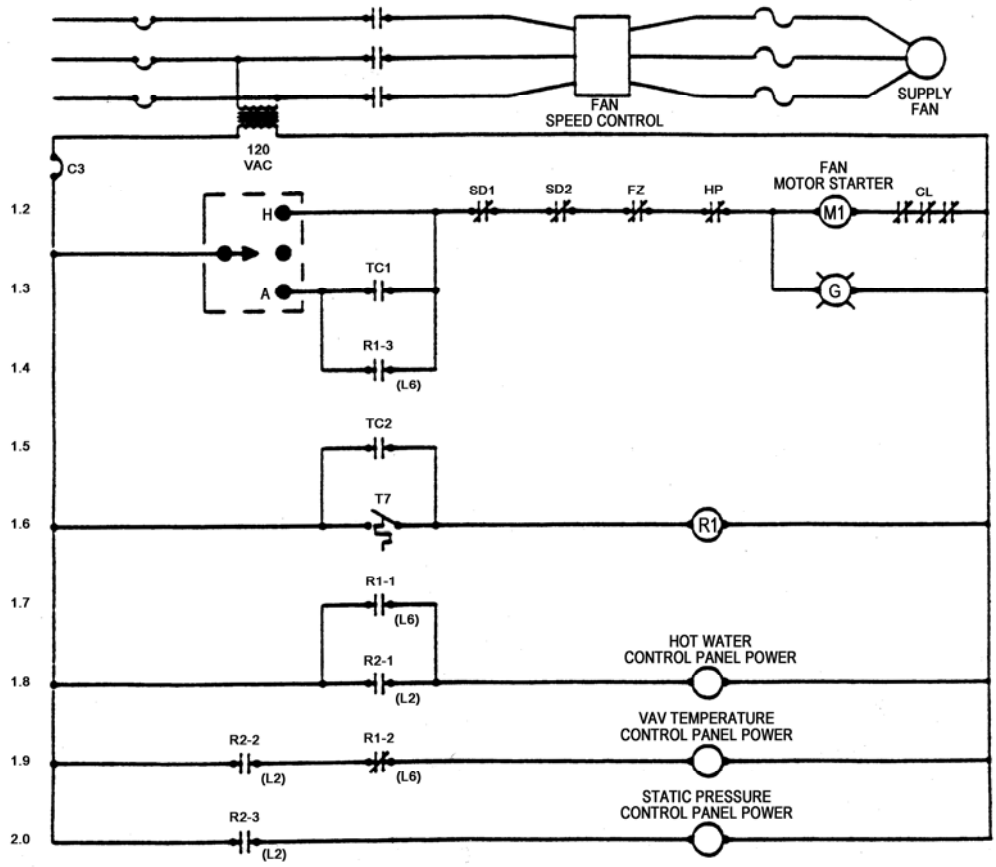

FAN
SPEED CONTROL
SUPPLY
FAN
120
VAC
C3
FAN
MOTOR STARTER
SD1
SD2
FZ
HP
CL
M1
G
H
A
TC1
R1-3
(L6)
TC2
T7
R1
R1-1
(L6)
R2-1
(L2)
HOT WATER
CONTROL PANEL POWER
R2-2
(L2)
R1-2
(L6)
VAV TEMPERATURE
CONTROL PANEL POWER
R2-3
(L2)
STATIC PRESSURE
CONTROL PANEL POWER
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0

Fig. G-3 >>

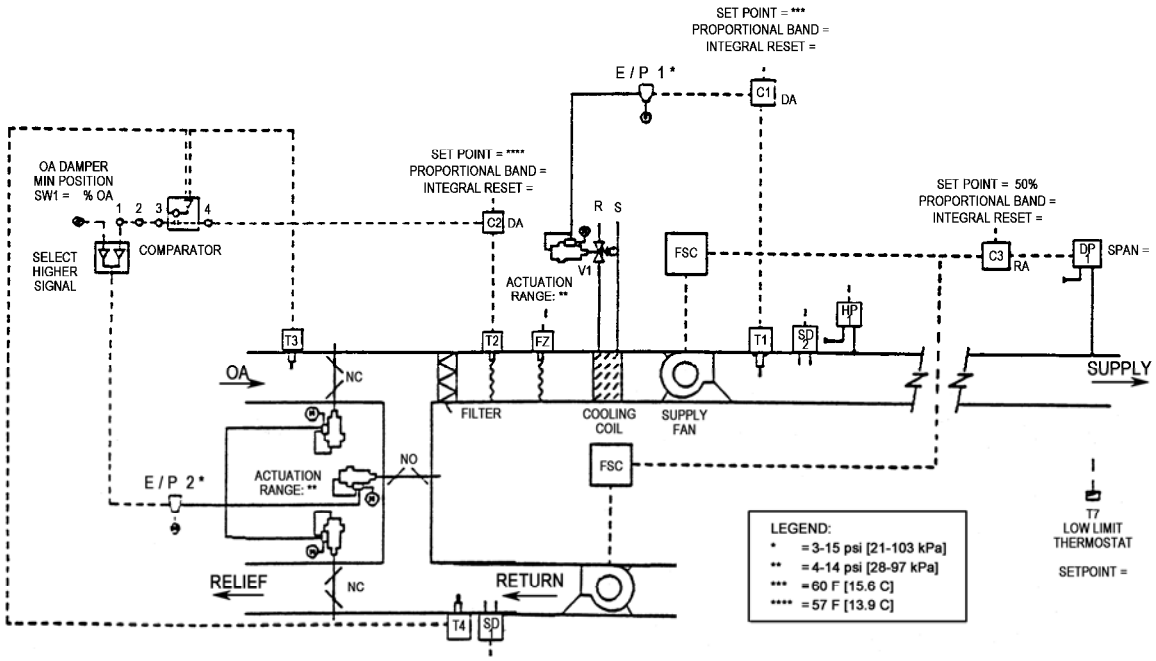

SET POINT = ***
PROPORTIONAL BAND =
INTEGRAL RESET =
E / P 1 *
C1
DA
OA DAMPER
MIN POSITION
SW1 = % OA
1 2 3 4
SELECT
HIGHER
SIGNAL
COMPARATOR
SET POINT = ****
PROPORTIONAL BAND =
INTEGRAL RESET =
C2
DA
R S
V1
ACTUATION
RANGE: **
FSC
SET POINT = 50%
PROPORTIONAL BAND =
INTEGRAL RESET =
C3
RA
DP
1
SPAN =
HP
T3
T2
FZ
T1
SD
2
OA
NC
FILTER
COOLING
COIL
SUPPLY
FAN
SUPPLY
E / P 2 *
ACTUATION
RANGE: **
NO
FSC
T7
LOW LIMIT
THERMOSTAT
SETPOINT =
LEGEND:
* = 3-15 psi [21-103 kPa]
** = 4-14 psi [28-97 kPa]
*** = 60 F [15.6 C]
**** = 57 F [13.9 C]
RELIEF
NC
RETURN
T4
SD

Fig. G-4 >>

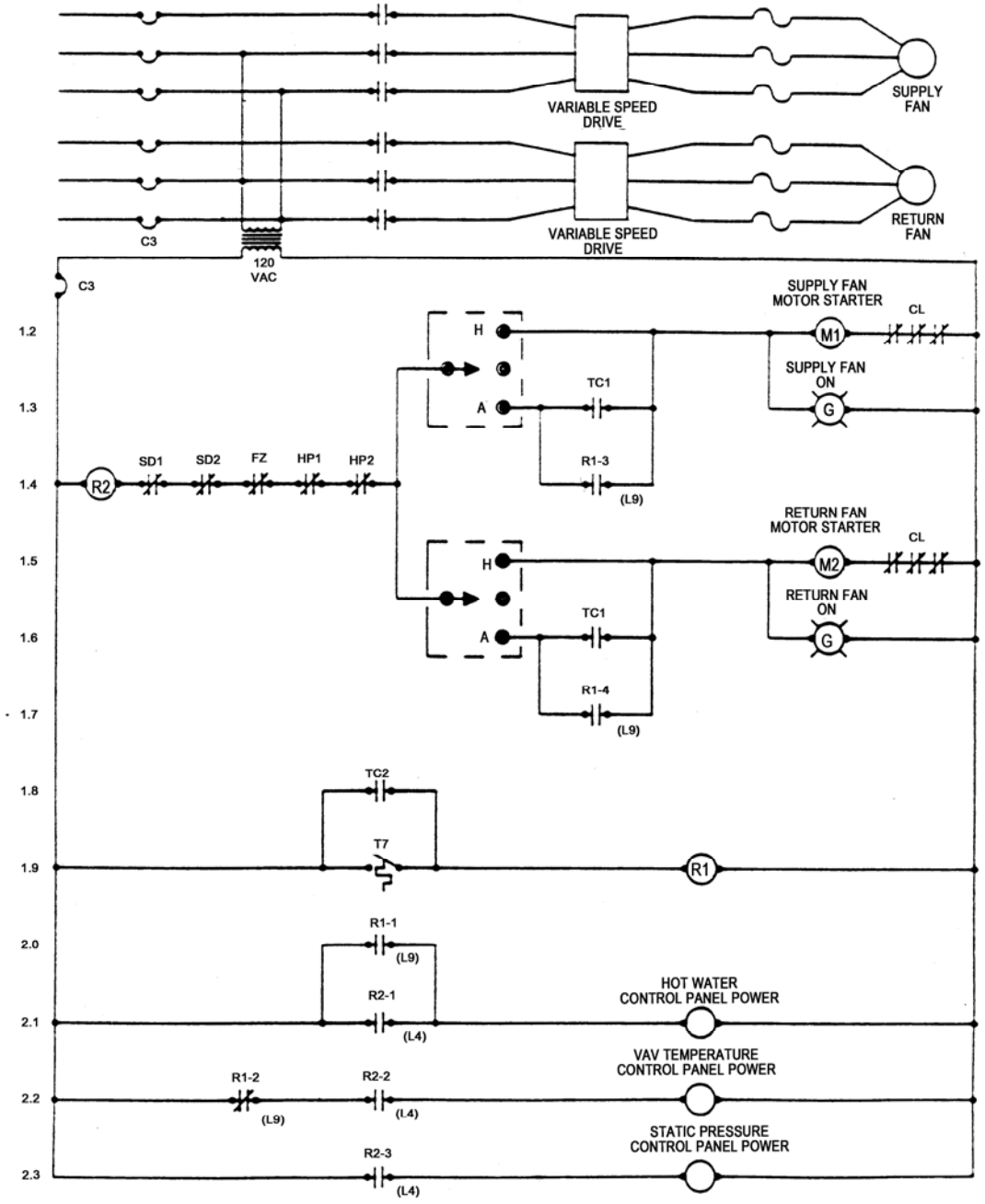

VARIABLE SPEED DRIVE
SUPPLY FAN
VARIABLE SPEED DRIVE
RETURN FAN
C3
120 VAC
C3
SUPPLY FAN MOTOR STARTER
CL
M1
SUPPLY FAN ON
G
H
A
TC1
R1-3
(L9)
SD1
SD2
FZ
HP1
HP2
R2
RETURN FAN MOTOR STARTER
CL
M2
RETURN FAN ON
G
H
A
TC1
R1-4
(L9)
TC2
T7
R1
R1-1
(L9)
R2-1
(L4)
HOT WATER CONTROL PANEL POWER
R1-2
(L9)
R2-2
(L4)
VAV TEMPERATURE CONTROL PANEL POWER
R2-3
(L4)
STATIC PRESSURE CONTROL PANEL POWER
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3

Fig. G-5 >>

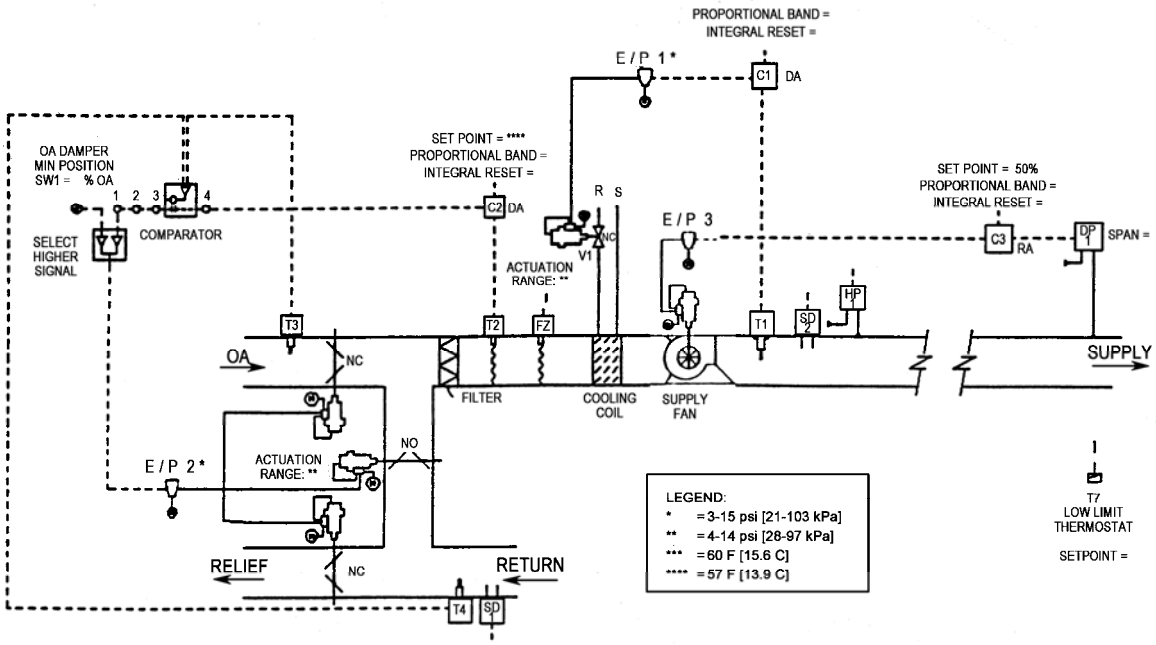

PROPORTIONAL BAND =
INTEGRAL RESET =
E / P 1*
C1
DA
OA DAMPER
MIN POSITION
SW1 = % OA
1 2 3 4
SELECT
HIGHER
SIGNAL
COMPARATOR
SET POINT = ****
PROPORTIONAL BAND =
INTEGRAL RESET =
C2
DA
R S
V1
NC
ACTUATION
RANGE: **
E / P 3
SET POINT = 50%
PROPORTIONAL BAND =
INTEGRAL RESET =
C3
RA
DP
1
SPAN =
T3
T2
FZ
T1
SD
2
HP
OA
NC
SUPPLY
FILTER
COOLING
COIL
SUPPLY
FAN
NO
E / P 2*
ACTUATION
RANGE: **
RELIEF
NC
RETURN
T4
SD
LEGEND:
* = 3-15 psi [21-103 kPa]
** = 4-14 psi [28-97 kPa]
*** = 60 F [15.6 C]
**** = 57 F [13.9 C]
T7
LOW LIMIT
THERMOSTAT
SETPOINT =

Fig. G-6 >>

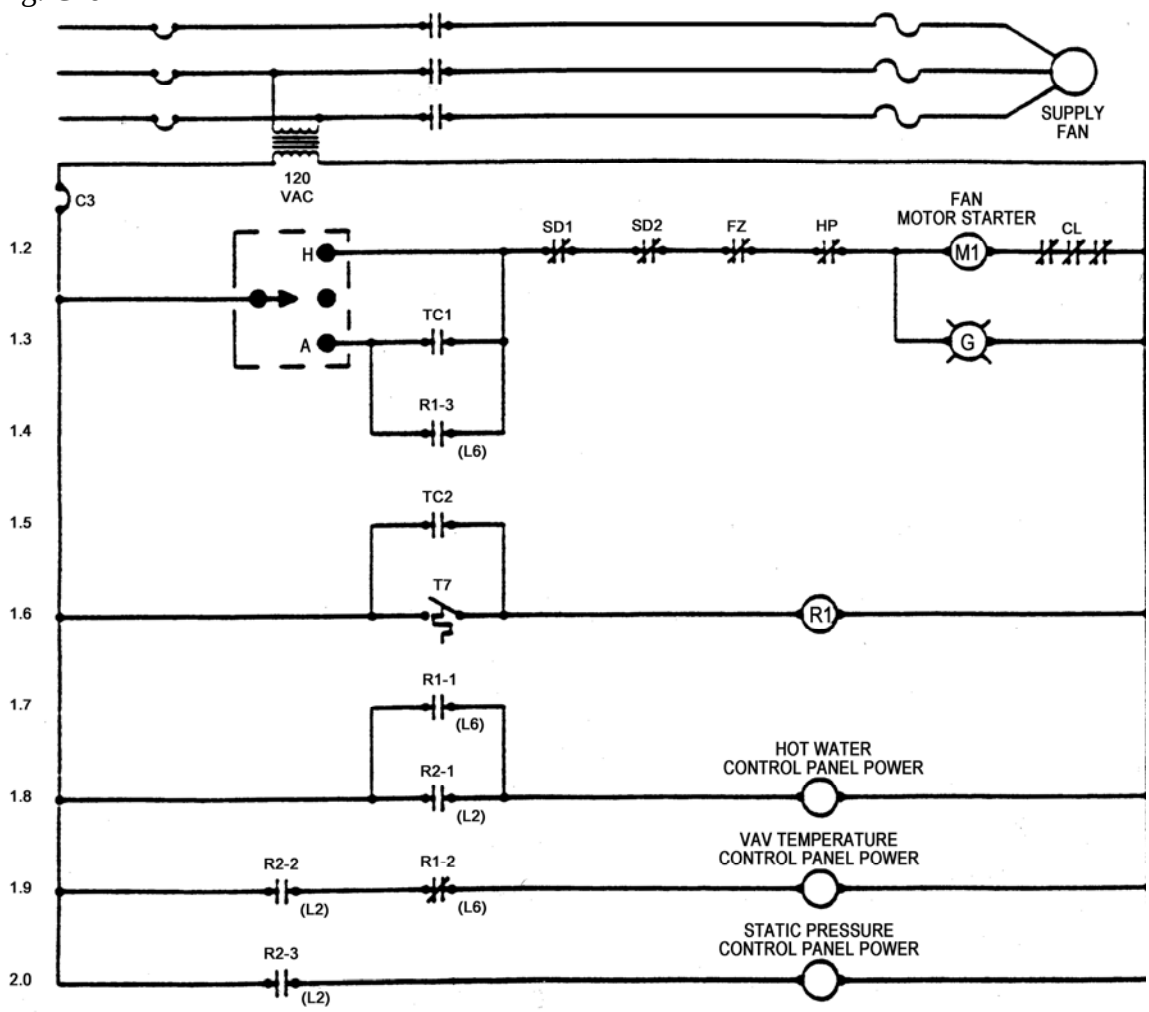

SUPPLY FAN
120 VAC
C3
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
H
A
SD1
SD2
FZ
HP
FAN MOTOR STARTER
M1
CL
G
TC1
R1-3
(L6)
TC2
T7
R1
R1-1
(L6)
R2-1
(L2)
HOT WATER CONTROL PANEL POWER
R2-2
(L2)
R1-2
(L6)
VAV TEMPERATURE CONTROL PANEL POWER
R2-3
(L2)
STATIC PRESSURE CONTROL PANEL POWER

Fig. G-7 >>

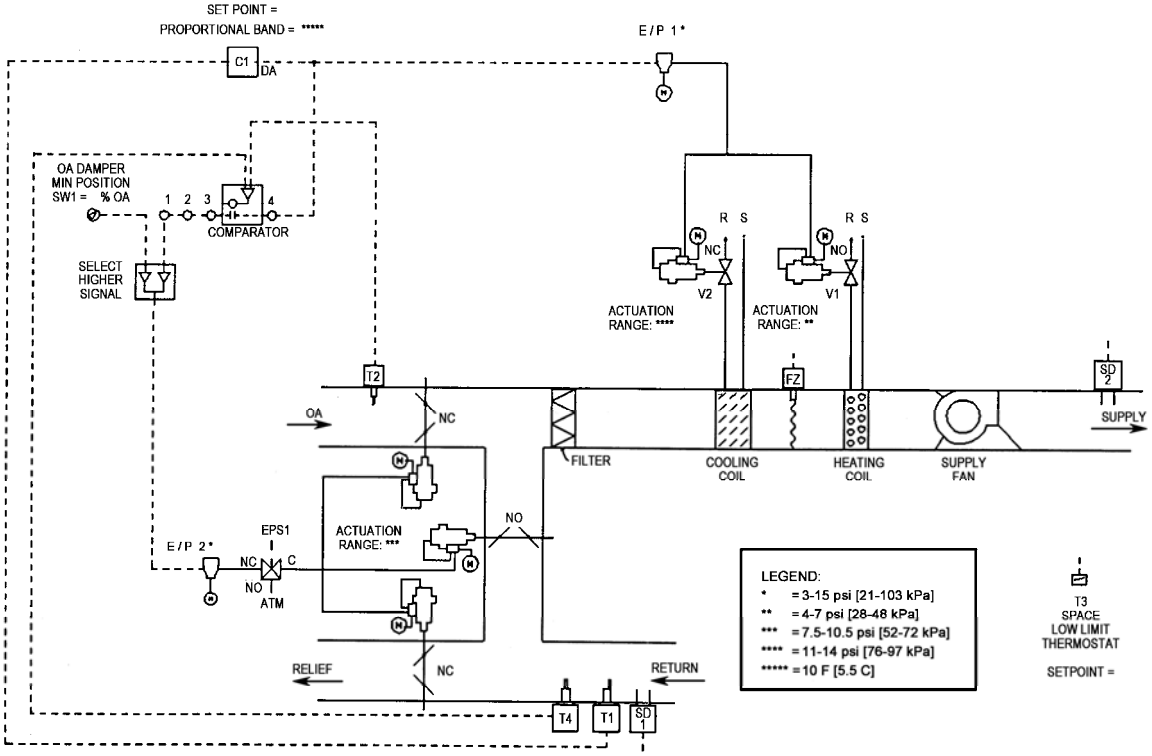


Fig. G-8 >>

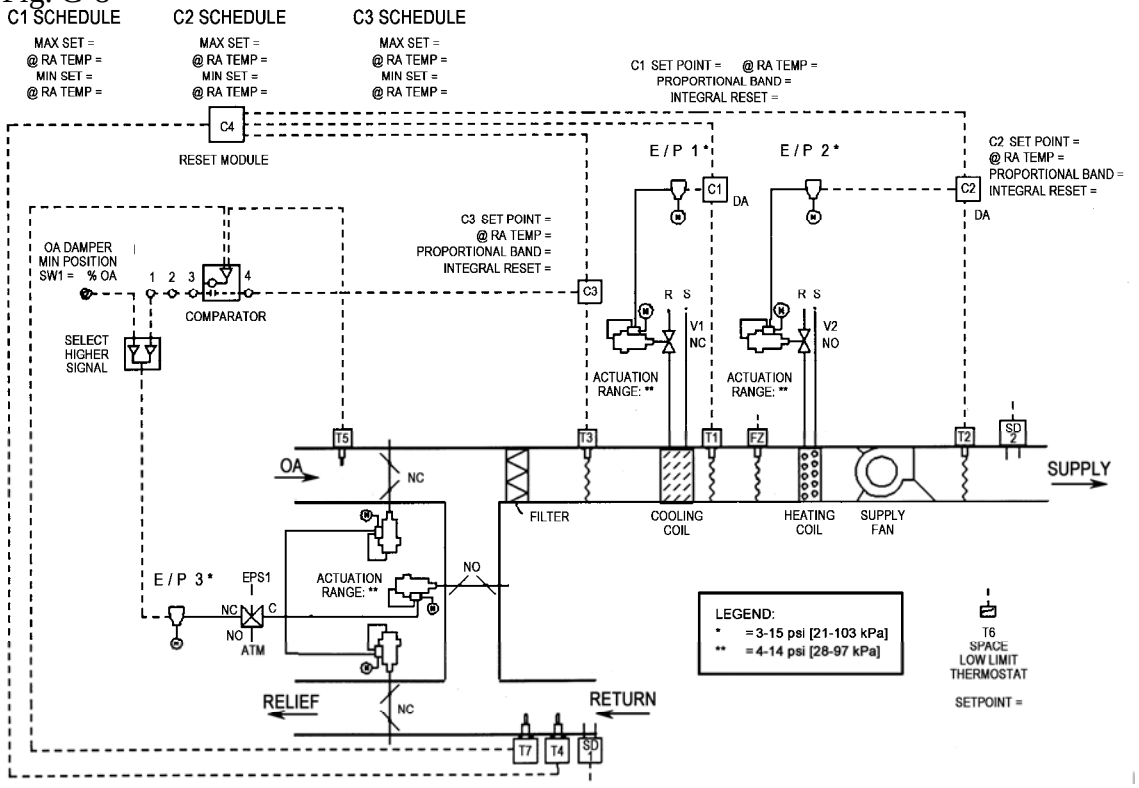


Fig. G-9 >>

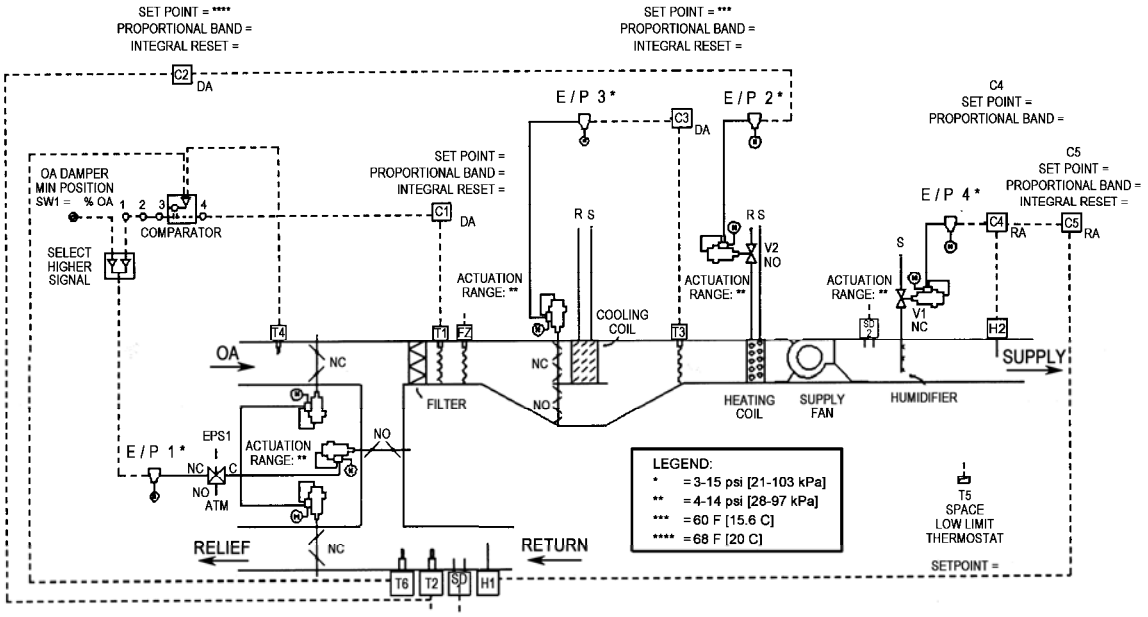

SET POINT = ****
PROPORTIONAL BAND =
INTEGRAL RESET =
C2
DA
SET POINT = ***
PROPORTIONAL BAND =
INTEGRAL RESET =
E / P 3*
E / P 2*
C3
DA
C4
SET POINT =
PROPORTIONAL BAND =
C5
SET POINT =
PROPORTIONAL BAND =
INTEGRAL RESET =
E / P 4*
C4
RA
C5
RA
OA DAMPER
MIN POSITION
SW1 = % OA
1 2 3 4
COMPARATOR
SELECT
HIGHER
SIGNAL
SET POINT =
PROPORTIONAL BAND =
INTEGRAL RESET =
C1
DA
R S
V2
NO
ACTUATION
RANGE: **
S
V1
NC
H2
SD
2
T4
T1
FZ
T3
OA
NC
NO
COOLING
COIL
FILTER
HEATING
COIL
SUPPLY
FAN
HUMIDIFIER
SUPPLY
E / P 1*
EPS1
NC
C
NO
ATM
ACTUATION
RANGE: **
RELIEF
RETURN
T6
T2
SD
1
H1
LEGEND:
* = 3-15 psi [21-103 kPa]
** = 4-14 psi [28-97 kPa]
*** = 60 F [15.6 C]
**** = 68 F [20 C]
T5
SPACE
LOW LIMIT
THERMOSTAT
SETPOINT =

Fig. G-10 >>

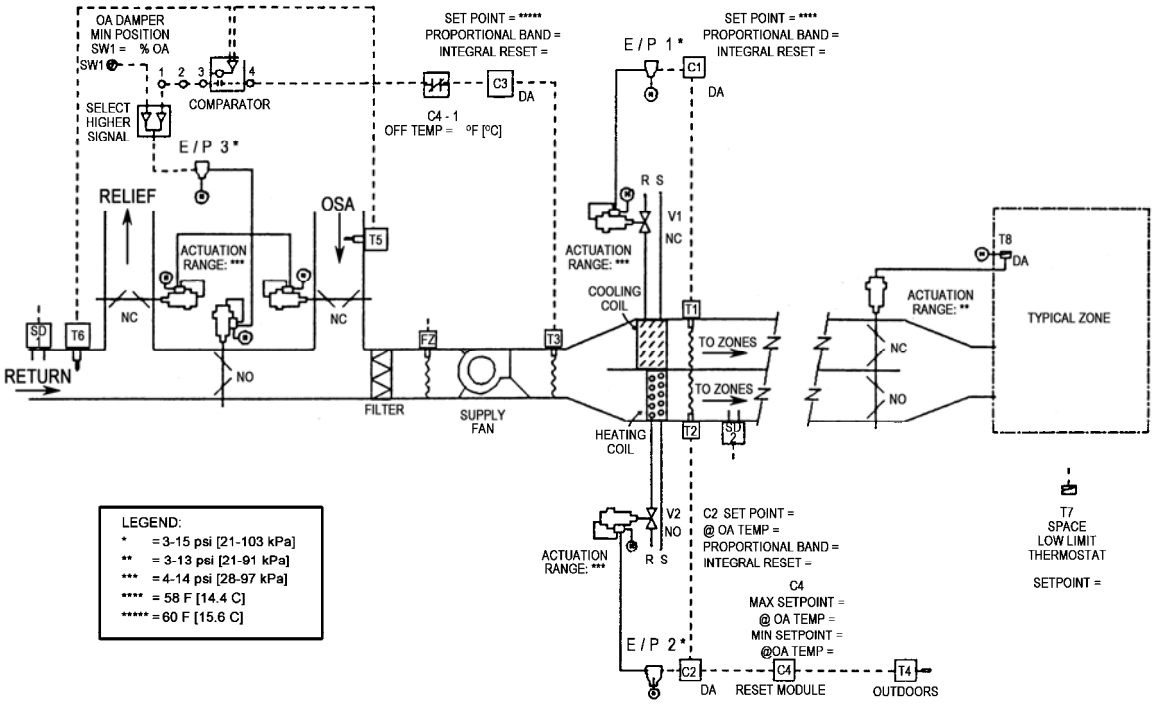
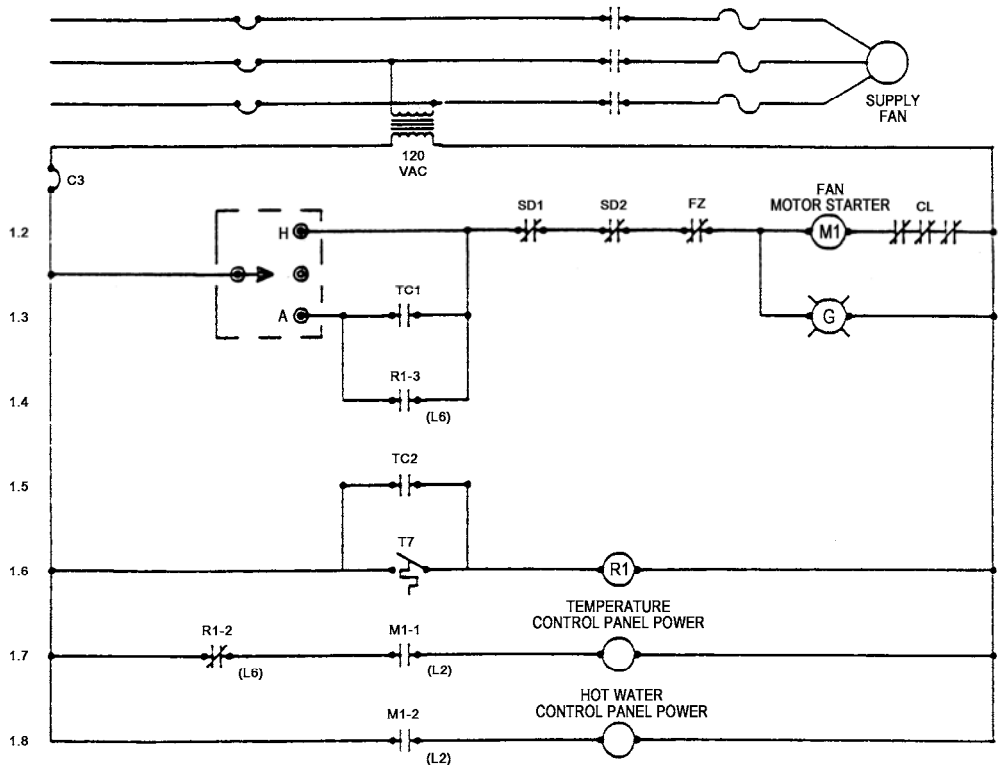

OA DAMPER
MIN POSITION
SW1 = % OA
SW1
1 2 3 4
COMPARATOR
SELECT
HIGHER
SIGNAL
E / P 3*
SET POINT = *****
PROPORTIONAL BAND =
INTEGRAL RESET =
C3
DA
C4 - 1
OFF TEMP = °F [°C]
E / P 1*
SET POINT = ****
PROPORTIONAL BAND =
INTEGRAL RESET =
C1
DA
R S
V1
NC
ACTUATION
RANGE: ***
COOLING
COIL
RELIEF
OSA
T5
ACTUATION
RANGE: ***
NC
NO
SD
T6
RETURN
FILTER
FZ
T3
SUPPLY
FAN
T1
TO ZONES
TO ZONES
HEATING
COIL
T2
SD
2
T8
DA
ACTUATION
RANGE: **
TYPICAL ZONE
NC
NO
T7
SPACE
LOW LIMIT
THERMOSTAT
SETPOINT =
LEGEND:
* = 3-15 psi [21-103 kPa]
** = 3-13 psi [21-91 kPa]
*** = 4-14 psi [28-97 kPa]
**** = 58 F [14.4 C]
***** = 60 F [15.6 C]
V2
NO
ACTUATION
RANGE: ***
R S
C2 SET POINT =
@ OA TEMP =
PROPORTIONAL BAND =
INTEGRAL RESET =
C4
MAX SETPOINT =
@ OA TEMP =
MIN SETPOINT =
@OA TEMP =
E / P 2*
C2
DA
C4
RESET MODULE
T4
OUTDOORS

Fig. G-11 >>


SUPPLY FAN
120 VAC
C3
1.2
1.3
1.4
1.5
1.6
1.7
1.8
H
A
SD1
SD2
FZ
FAN MOTOR STARTER
CL
M1
G
TC1
R1-3
(L6)
TC2
T7
R1
TEMPERATURE CONTROL PANEL POWER
R1-2
(L6)
M1-1
(L2)
HOT WATER CONTROL PANEL POWER
M1-2
(L2)