Introduction to the HVAC Zoning and Vent Control App

potential names:

* VentZone
* HVAC-Z
* SmartFAZe (Forced Air Zoning)

<summary of features>

<existing control hardware does not have access to the information that is available in a smart home, so it doesn’t control the system as intelligently as is possible>

<also, it is expensive to include options in hardware, so only a few configuration options are provided by commercial zone controllers>

<hub-based zone control is subject to interruptions such as reboots and loss of radio signals. There are ways to mitigate these and prevent a freezing house.>

<ability to use the features separately>

<why are these in a single app – because they are inter-related>

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Forced Air HVAC Systems

Figure 1 illustrates an air handler, which is the heart of a forced air Heating, Ventilation, and Air Conditioning (HVAC) system. An air handler includes a blower which draws air from return ductwork and propels it through at least one heat exchanger and through supply ductwork to various rooms in a residence. In the air handler illustrated in Figure 1, there are two heat exchangers: a furnace to heat the air during cold weather and an air conditioning evaporator to cool the air during hot weather. Only one of the two heat exchangers would be used at a time. In climates that do not need both heating and cooling, one of the two heat exchangers may not be present. Also, some air handlers use a heat pump heat exchanger which can alternately provide either heating or cooling. (Note: the App does not currently support heat pumps.)

The air handler also includes controls which receive signals indicating when to provide heating, cooling, or fan. As will be discussed later, these signals may come directly from a thermostat or may come from a zone controller. If air conditioning is present, the controller will send signals to a compressor unit that is located outdoors. In response, the compressor will circulate refrigerant through refrigerant lines to the evaporator.

Some air handlers provide two stages of heating, cooling, or both. The first stage usually provides about 60% as much heating or cooling capacity as the second stage, although the percentage varies between models. When the full capacity is not needed to maintain the desired temperature, using the first stage is more efficient and provides better comfort. There are various control strategies for deciding when to use first stage and when to use second stage. A common strategy is to use first stage for a set amount of time (10 to 12 minutes) and then go to second stage for the remainder of the heating or cooling call. More sophisticated strategies require more inputs. Modulating equipment can adjust capacity to effectively any level between a minimum capacity and a maximum capacity. (Note: the App does not currently support modulating equipment.)

Many ventilation systems utilize the air handler to circulate fresh air from outdoors throughout the residence. In these systems, the fresh air enters the system via the return ductwork. Ventilation will be discussed in more detail later.

Blower

Filter

Furnace

AC Evaporator

Supply Ductwork

Return Ductwork

Ventilation

Air Handler

Controls

Compressor Calls

Heating Calls

Cooling Calls

Fan Calls

Refrigerant Lines

To Compressor

Fig. 1 - Air Handler

Zoned and Un-zoned Duct Systems

Figure 2 shows the supply side of a typical un-zoned forced air HVAC system. The air handler takes in air from a return duct (not shown), and then blows heated or cooled air into a plenum. From the plenum, the air flows through one or more trunk ducts. Branch ducts conduct the air from the trunk ducts to registers in individual rooms. Air from the rooms then flows back to the air handler through the return ducts.

A thermostat measures the temperature of the air and compares it to a heating setpoint, a cooling setpoint, or both. In heating mode, when the air is cooler than the heating setpoint, the thermostat sends a heat call to the air handler, causing the air handler to run in heating mode to warm up the interior air. Once the air at the thermostat is warmer than the heating setpoint, the heating call ends and the air handler shuts off. To avoid cycling on and off too frequently, the thermostat doesn’t call for heat until the air is a little less than the setpoint and doesn’t end the heat call until the air temperature exceeds the setpoint by some margin. Cooling mode works similarly. The thermostat calls for cooling when the air temperature is a little above the cooling setpoint and ends the cooling call when the air temperature has decreased below the cooling setpoint by some margin.

Designers of the duct system try to set up airflow rates to each room based on average heat loss (or gain) rates. Upstairs rooms tend to have high cooling loads relative to their heating loads. If the designer sets the airflow to these rooms based on heating loads, they end up being under-cooled during summer. If, on the other hand, the designer sets the airflow to these rooms based on cooling loads, then they tend to be over-heated during winter. The designer may end up picking a middle level with the result that the upstairs rooms end up a little too warm all year. Basements, on the other hand, tend to have very low cooling loads relative to their heating loads.

Sometimes, a few rooms may temporarily have unusually high internal heat gains, for example from sunshine coming in particular windows, people gathering in particular rooms, cooking, running a fireplace, etc. Designers of un-zoned ductwork cannot do anything about these temporary differences between rooms. The system makes the space around the thermostat comfortable but other spaces may be uncomfortably warm or cold.

Air Handler

Plenum

Trunk

Master Bedroom

Master Bathroom

Bedroom 1

Bedroom 2

Bathroom

Kitchen

Laundry

Bathroom

Family Room

Dining Room

Branch Duct

 Tstat

Fig. 2 - Single Un-zoned Ducted HVAC system

Figure 3 shows a HVAC system with two independent air handlers and duct systems. This solves the problems with upstairs and downstairs having different loads. The upstairs system may have a larger air conditioning capacity and a smaller heating capacity than the downstairs system. The upstairs system uses its own thermostat, so it runs when and only when air upstairs needs conditioning. There can still be variations between rooms on each of the floors based on unequal internal gains.

A drawback of this approach is that it requires two air handlers and, usually, separate air conditioning compressors. These tend to be the most expensive parts of the system. Although the equipment can be smaller, two units are considerably more expensive than one unit with double the capacity. This setup is common in two story houses in regions of the country where basements are not common. It is uncommon for a residence to have more than two independent ducted systems.

Air Handler

1

Plenum

Trunk 1

Master Bedroom

Master Bathroom

Bedroom 1

Bedroom 2

Bathroom

Kitchen

Laundry

Bathroom

Family Room

Dining Room

Trunk 2

 Air Handler

2

Plenum

 Tstat

 Tstat

Fig. 3 - Multiple Un-zoned Ducted HVAC systems

Figure 4 shows a two-zone ducted HVAC system. Like the dual un-zoned system of Figure 3, the upstairs rooms and downstairs rooms are served by separate trunk ducts. However, both truck ducts are served by a single air handler. Zone dampers open and close to either allow air to flow into a truck duct or block air from flowing into a trunk duct. Each zone has a separate thermostat. A zone controller takes in commands from the thermostats and sends commands to the air handler and to the zone dampers.

If the downstairs thermostat is calling for heat but the upstairs thermostat is not, the zone controller opens the damper for the downstairs, closes the zone damper for the upstairs, and commands the air handler to produce heat. If both zones call for heat, the zone controller opens both zone dampers. If the zones have conflicting calls, the zone controller must choose which call to serve. Most commonly, this happens when one zone calls for heating or cooling while the other zone calls for fan only. In that case, the zone controller would likely give the heating or cooling call preference and ignore the fan command until the heating or cooling call is satisfied. It is rare to have one zone call for heating while another zone calls for cooling, but it can happen. In that case, the zone controller must alternate or give one type of call preference.

Two zone and three zone residential systems are common. However, it is problematic if any zone is too small relative to the size of the whole system. The air handler must be sized to serve the design heating and cooling loads of the whole house. When only the small zone is calling for heating or cooling, the air handler may produce more airflow than the single zone can handle. Pushing that much air through a single trunk duct and a few branch ducts may result in excessive pressure which can be harmful to the fan motor. It may also be noisy. This problem is exacerbated if the residents shut off the airflow to some of the registers, either intentionally or by blocking them with furniture or something else.

In addition to avoiding small zones, there are a few things a system designer can do to mitigate the small zone issue. Some systems have a bypass duct between the plenum and the return duct with a damper that automatically opens if the pressure exceeds a threshold. Opening this damper reduces the amount of air going through the remainder of the ductwork. However, the air flowing into the air handler is warmer in winter and cooler in summer which can be problematic. In summer, the cooler air entering the air handler increases the likelihood of frost on the heat exchanger coils, making the heat exchanger much less efficient, and possibly causing equipment damage. (see <https://www.greenbuildingadvisor.com/article/the-achilles-heel-of-zoned-duct-systems> )

A better remedy is to adjust the closed position of some of the dampers such that some air flows into those zones even when they are not calling for heating or cooling. That works as long as the residents don’t close off registers.

Air Handler

Plenum

Trunk 1

Master Bedroom

Master Bathroom

Bedroom 1

Bedroom 2

Bathroom

Kitchen

Laundry

Bathroom

Family Room

Dining Room

Trunk 2

 Zone Controller

 Tstat

 Tstat

Zone Damper

Controllable Register

Duct Fan

Fig. 4 - Zoned Ducted HVAC system

Residents often do modify the duct system. They may have rooms that they use infrequently, and they want to keep those rooms less conditioned to reduce heating and cooling bills. Sometimes, a room may tend to run warm or run cold relative to other rooms. As shown in Figure 4, there are controllable registers for the dining room on the first floor and for one of the bedrooms on the second floor. These may be electronically controlled, such as Keen (see <https://keenhome.io/pages/how-it-works> ). When these are closed, the respective zone effectively gets even smaller. It may end up smaller than the duct system designer planned for. Another possible modification is a duct fan to increase airflow to under-served rooms, such as a room that is far from the air handler.

Zone Control and Equipment Control in the App

General Principles of Operation

Like a conventional zone controller, the App receives requests from each zone, decides which requests it can serve, then selects the zones to be served and commands the equipment accordingly. In a conventional zone controller, the requests are binary. A zone is either requesting heat or not requesting heat. With the App, the zone requests a specified airflow rate. The App ensures that no more than the requested airflow rate is delivered to that zone. To accomplish this, the App needs information about the airflow capacity of each zone and the airflow provided by the equipment. This information is entered during setup. Exact data is not needed to make the system function properly. Rules of thumb should typically be adequate, as discussed in the sections below about describing your system to the App. These settings can be changed later if necessary.

For two-stage equipment, the App generally uses only first stage as often as possible because that is most efficient and provides the greatest comfort. The App commands second stage when necessary to keep up with especially high demand or to accomplish a significant change in temperature, such as when recovering from a setback.

There are a number of opportunities for users to specify how the App should handle various situations. App settings are employed for user inputs that would be changed infrequently once the system is set up. For inputs that are likely to change on a frequent basis, the App uses switch devices. The user indicates what switch to use during setup and then manipulates the switches as desired during use. Most often, virtual switches are preferred over physical switches for this purpose. The user may turn these switches off and on via a dashboard or may set up rules to set the switches based on conditions sensed by other devices. In this way, behavior of the HVAC system may react indirectly to inputs never envisioned by the App programmer.

Similarly, the App outputs are switch devices. During setup, the user specifies which switches the App should set for each output. In some cases, the user may specify a physical switch that directly controls system. In other cases, the user may create a virtual switch and link that switch to physical devices through rules.

The App is structured hierarchically. There is a main App which controls the equipment and child apps for each zone. Any subzones, such as controllable registers (i.e. Keen vents) or duct booster fans are handled by another level of child apps under the corresponding zone app. Like other home automation apps, there is no user interface. However, it is useful to set up a dashboard with all of the input and output devices.

Ventilation

Indoor air tends to get polluted over time due to activities inside the house. Breathing reduces the concentration of oxygen and increases the concentration of carbon dioxide. Activities like cooking tend to produce Volative Organic Compounds (VOCs) some of which are unhealthy. Some items within a home may off-gas hazardous VOCs. Therefore, it is necessary to regularly exchange stale indoor air for fresh outdoor air. However, excess air exchange increases the heating and cooling loads and costs. Older homes typically are not very airtight, so these homes often experience excessive air exchange, leading to higher heating and cooling cost. To combat these costs, builders have learned how to build houses that have low air leakage. In newer homes or homes that have been upgraded to be more airtight, it is necessary to use mechanical systems to intentionally bring in an appropriate amount of fresh outdoor air.

There are several types of mechanical ventilation systems. An exhaust only system uses a fan, such as a bathroom fan, to blow air out of the house. That depressurizes the inside of the house causing air to come in wherever there are leakage paths. Supply ventilation, on the other hand, uses a fan to blow outdoor air into the house, pressurizing the house and causing air to leave through leakage paths. Balanced systems blow approximately equal amounts of air into the house and out of the house. With a Heat Recovery Ventilator (HRV), the incoming and outgoing air streams go through a heat exchanger such that the incoming air in preconditioned to be near the same temperature as the outgoing air. Enthalpy Recovery Ventilators (ERVs) exchange both heat and moisture between the air streams.

With supply ventilation and balanced ventilation, the incoming fresh air should be distributed around the house. (Exhaust ventilation doesn’t provide an opportunity to control how fresh air is distributed.) Some systems use separate ventilation ductwork to distribute the fresh air. In other systems, the fresh air is injected into the return ductwork, as shown in Figure 1, and the air handler distributed the fresh air through the supply ductwork. This is referred to as an interconnected ventilation system. Interconnected ventilation systems are cheaper to install than systems with separate ductwork. However, the operating costs are higher because the blower must run more than it otherwise would in order to distribute the fresh air.

The fraction of time that a ventilation system needs to run depends on what is happening in the house. When there are many guests in the house for a holiday meal, a lot of ventilation is needed. When only a couple people are in the house, a moderate amount of ventilation is needed. If the residents decide the outdoor temperature is comfortable enough to open windows, no mechanical ventilation at all is needed. However, conventional ventilation controls don’t have access to information about what is happening in the house, so typically an average amount is selected.

In an interconnected ventilation system, it is best to coordinate ventilation with heating and cooling. For example, if the ventilation system should run 30% of the time and the heating system needs to run 30% of the time, it is best if these are the same 30%. If there is complete coordination, the blower only needs to run 30% of the time. Without coordination, the blower could run as much as 60% of the time.

Vent Control Logic in the App

<percentage time control – non-interconnected>

<percentage time control – interconnected>

<power of using app is adjusting percentage based on number of people>

<force ventilation>

Running with equipment

not in end-phase

Runtime complete

(implies not running)

(equipment may be on or not)

Waiting - Not running

runtime not complete

(implies equipment off)

E: Runtime reached

A: turn off vent

E: Equipment off

A: turn off vent, schedule deadline event

E: Equipment on

A: turn on vent, schedule runtime reached event

End Phase

(implies running)

(equipment may be on or not)

E: Deadline

A: turn on vent and fan

E: New Interval

E: New Interval

A: turn off fan

Equipment running

A: turn on vent (if off)

Equipment not running

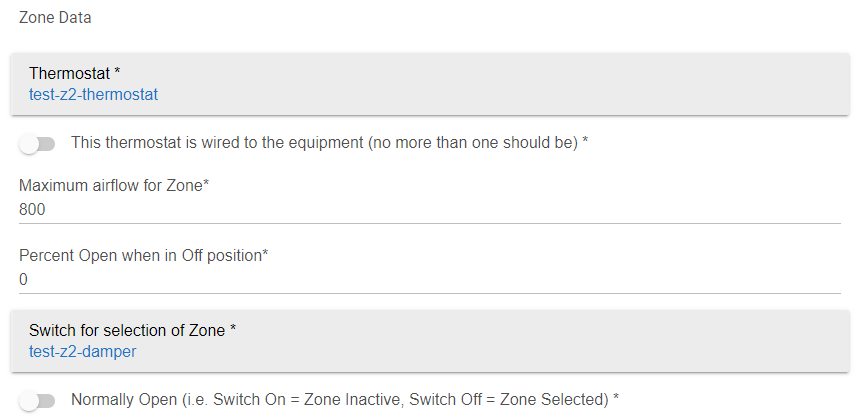
A: turn off vent (if on)

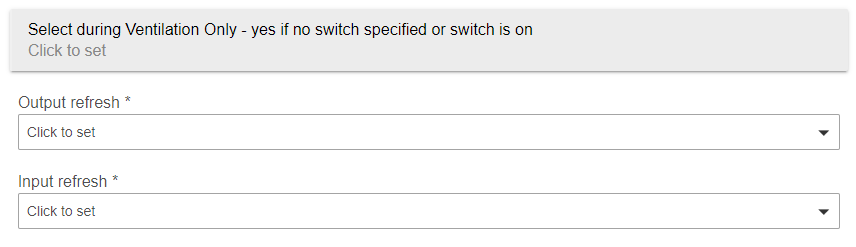
Fig. ? – Vent Control Logic

Downloading, Installing, and Configuring the App



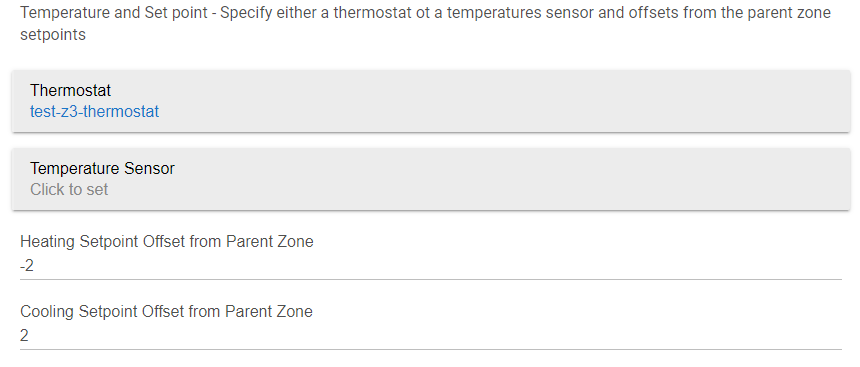
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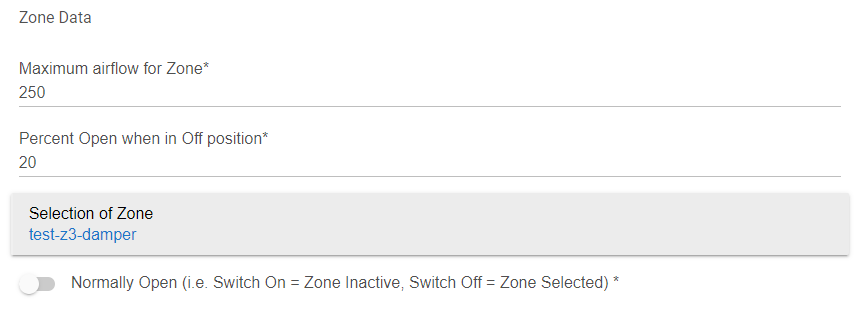


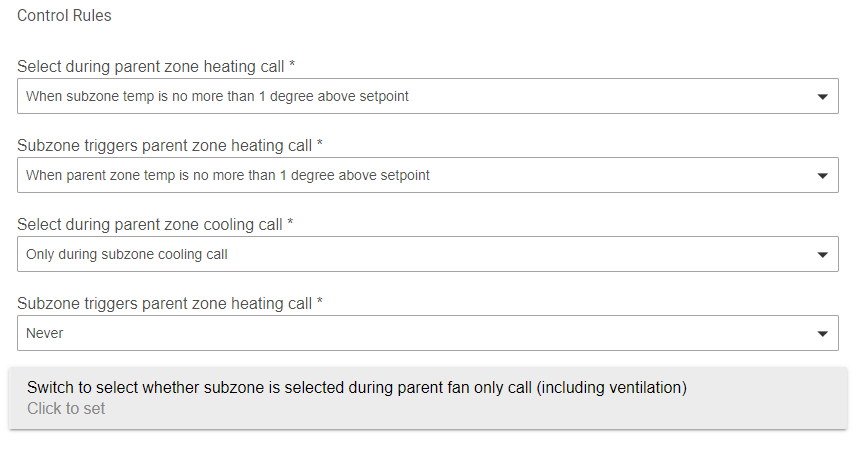




<setting up subzones>



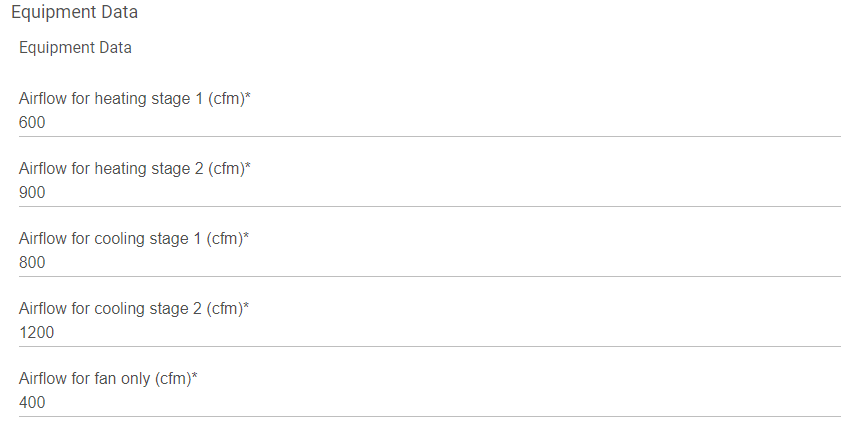




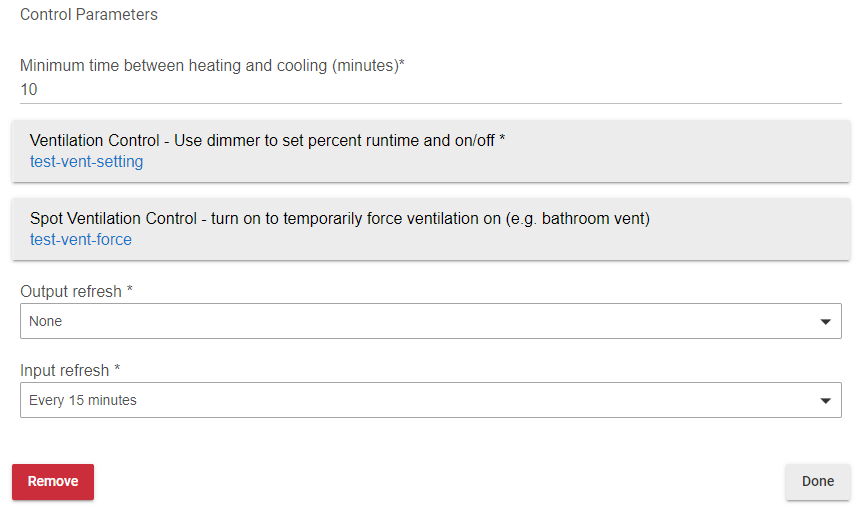
<defining equipment – including stages>

<staging control – if furnace will control staging, tell app it is single stage and use second stage for airflow>









<zones too small for air handler>

Recommendations for Device Setup

Preliminary Considerations

<need good thermostat>

<zone dampers – normally open or normally closed>

Examples

<illustrate ventilation control only on unzoned system>

<smart plug for ERV, command thermostat for fan interlock>

R B W1 Y1 G

Air Handler

Neutral

Heating Calls

Cooling Calls

Fan Calls

Thermostat

R B W Y G

HRV / ERV

Smart Plug

24V AC

Vent Calls

Virtual Switch

Heating Calls

Cooling Calls

Fan Calls

Zone Select

Virtual Switch

Virtual Switch

Virtual Switch

No Physical Impact

Existing Wiring

Rule

<illustrate ventilation and staging control on unzoned system>

<ZEN16 for stage2 and vent (CFIS damper), command thermostat for fan interlock >

R B W1 W2 Y1 Y2 G

Air Handler (update switches)

Neutral

Heating Calls

Cooling Calls

Fan Calls

Thermostat

R B W Y G

R3 R3 R2 R2 R1 R1 - +

Zooz ZEN16

24V AC

Vent Calls

Virtual Switch

Heating Calls

Cooling Calls

Zone Select

Virtual Switch

Virtual Switch

No Physical Impact

Existing Wiring

2nd Stage Cooling

2nd Stage Heating

Ventilation Damper

Fan Calls

Virtual Switch

Rule

<illustrate system with one primary zone and three subzones>

<using ZEN16 for heating and cooling calls allows subzones to initiate. Existing wiring is backup>

<wired-OR and auto turn-off of ZEN16>

R B W1 Y1 G

Air Handler

Neutral

Heating Calls

Cooling Calls

Fan Calls

Thermostat

R B W Y G

R3 R3 R2 R2 R1 R1 - +

Zooz ZEN16

24V AC

Vent Calls

Zone Select

Virtual Switch

No Physical Impact

Existing Wiring

Cooling Calls

Heating Calls

Ventilation Damper

Fan Calls

Virtual Switch

Rule

KEEN Vent

Subzone 2 Select

Duct Fan

Smart Plug

Subzone 3 Select

KEEN Vent

Subzone 1 Select

<illustrate fully wireless 3 zone system with ZEN16 relays>

R B W1 W2 Y1 Y2 G

Air Handler (update switches)

Neutral

Heating Calls

Cooling Calls

Fan Calls

R3 R3 R2 R2 R1 R1 - +

Zooz ZEN16

24V AC

Vent Calls

Zone 3 Select

2nd Stage Cooling

2nd Stage Heating

Ventilation Damper

R3 R3 R2 R2 R1 R1 - +

Zooz ZEN16

Zooz ZEN16

+ - R1 R1 R2 R2 R3 R3

Zone 3 Damper

Zone 2 Damper

Zone 1 Damper

Zone 2 Select

Zone 1 Select

Features still to be implemented before initial release:

* Periodic polling of inputs in case any signals are missed – coded but not tested
* Periodic repeating of output signals so auto-shutoff of ZEN16 can be used – coded but not tested
* Control over which zones are turned on for ventilation – need to check enough capacity selected
* Option to not count heat calls in some zones toward ventilation runtime
* Ensure desired behavior of dampers during idle
* Delay before selecting second stage
* Make sure second stage not selected for awhile after an overpressure
* Select second stage in response to temperature delta from setpoint (check only on setpoint change)
* Fan only mode doesn’t activate ventilation – check whether completely implemented, especially in start\_vent\_interval()
* Comment out debug statements

Features to be considered for future releases:

* Non-binary zone dampers (especially for subzones)
* Support for heat pumps
* Support for modulating equipment
* Control of humidifiers and/or dehumidifiers