ApacheHVAC: Tight controls for space temperature and humidity

Whereas space temperature controls for maintaining human thermal comfort typically have a deadband of several degrees between heating and cooling setpoints, plus an allowance for control of airflow, water, coils, etc. as the space temperature strays outside of the band defined by the setpoints, projects such as museum archives and laboratories may require considerably tighter controls.

- While there are exceptions for buildings where tight control is critical (labs, museums, certain health-care applications, etc.) ASHRAE standard 90.1 requires at least 5°F between the heating and cooling setpoints to allow for a deadband and to avoid wasting energy on overly tight control (assuming this is simply for human thermal comfort). It is also important to maintain some control bandwidth so that there is a range of temperature over which controls can modulate thermal inputs to the space. In publication DA28 Building Management and Control Systems from AIRAH, the Australian equivalent of ASHRAE, the recommendation for VAV applications is a minimum of 1K actual (truly neutral) deadband between any control actions, plus control ramp bandwidths of at least 1K each for both heating and cooling controls. With setpoints occurring in the middle of the two control bands, this translates to heating and cooling setpoints separated by at least 2K.

- Among the four most common errors listed for VAV system control in actual building, AIRAH includes “Small or non-existent deadbands lead to excessive instability.” The one case where AIRAH suggests there might be less difference between heating and cooling set points is with PID controllers, which can provide tighter control without excessive energy consumption but are expensive to set up and thus less common outside of process applications. PID controls can only be approximated by proportional controls modeling, and even with PID controls and high-quality sensors, the actual control system will need some bandwidth over which to control dampers, coils, etc. Furthermore, this tendency toward instability for very tight controls is exaggerated in simulation, as reality has an unlimited number of time steps over which to make tiny corrections whereas a whole-building simulation will use time steps somewhere between 1 minute and 60 minutes (typically 6 to 10 minutes for the VE).

The pre-defined controls and HVAC profiles require a minimum of 4 F (2.22 K) between the heating and cooling setpoints to avoid overlap of controls, and using this minimum value would provide zero actual deadband (one or the other control would always be active).

Continued below...
The graphic above from the ApacheHVAC user guide section 8.3.15 VAV airflow controls shows the relationship of the standard pre-defined control midbands and bandwidth relative to zone heating and cooling setpoints. In this example, the heating and cooling setpoints are separated by 6°F, and it can be seen that the ramps for cooling airflow and heating coil control will overlap if this difference is reduced by more than 2°F.

If you require tighter control than is allowed by the pre-defined controls, you must either 1) modify the HVAC control bandwidths and/or 2) modify the HVAC control profiles, depending on the intended outcome.
1. To reduce the control bandwidths, simply modify the values for Proportional Bandwidth. As with any controller parameter within the zone-level multiplex region of the system, this can be executed as a global edit, a local edit, or via tabular edit by clicking the parameter label when in global edit mode.

- Reducing the cooling airflow control band from the default 2 F to 1 F without adjusting the midband profile would allow the heating and cooling setpoints to be moved 0.5 F closer without overlap (i.e., to a minimum separation of 3.5 F).
- If the same change from the default 2 F to just 1 F was made in the zone re-heat coil controller, this will shave another 0.5 F from the required separation, allowing the setpoints to be just 3.0 F apart without overlap.
- The reduced minimum required separation of setpoints noted in the examples above assumes that it is acceptable to have no actual deadband at all. This will tend to lead to control instability, particularly if using relatively large simulation time steps, and potentially forcing simulation with very small time steps (1 or 2 minutes) to avoid modeling excessive energy consumption as a result of unstable zone temperatures and the absence of an actual deadband.
While it will not change the required separation of setpoints, similarly reducing the bandwidths for Cooling SAT reset and Heating airflow controls will reduce the overall throttling range, and thus apply the full potential of system heating and cooling over a narrower range of zone temperatures. Again, there is some risk of added instability, but not nearly so much or with such energy-intensive implications as eliminating the deadband between heating and cooling controls.

2. To adjust the control midbands closer to the heating and cooling setpoints, you will need to manually edit the HVAC profiles in the ApPro database.

**IMPORTANT NOTE:** The System Schedules dialog, which can be a valuable tool prior to manual edits, should *not* be used to edit or assign edited profiles *after* manually editing, as this will overwrite manual edits.

As of VE 2012 Feature Pack 1, the System Schedules & Setpoints dialog includes a facility for *assigning* any alternate set of set-point and HVAC profiles to selected zone groups and/or HVAC systems. To avoid overwriting manual edits, it is essential that you create *and* assign an alternate profile set *before* manually editing them to adjust the throttling range, and thereafter ensure that you do not click OK or Apply in the System Schedules dialog when the modified set of profiles is selected. The dialog is not (yet) capable of editing the profiles for any throttling range expect the default, and it will overwrite your manual edits with defaults for this aspect of the profiles if you click either OK or Apply.

For the same reasons, it will also be valuable to use the System Schedules dialog to edit HVAC operating hours, morning start-up, after-hours operation, and control strategy for night/unoccupied operation *before* manually editing the profiles.
Manual editing of HVAC profiles to alter the midband offsets from setpoint and thus modify this aspect of the throttling range

The table in ApacheHVAC User Guide Appendix B: HVAC zone controller profile values relative to setpoints entered in the System Schedules dialog is helpful in quickly identifying which profiles need to be modified for a particular system type (listed in the first column). The associated profiles are indicated as “HP2, HP5, CP1, CP7” corresponding to the profile names in the ApPro database view. For each system type category, the table indicates in a column for each relevant control the midband values relative to setpoint, which profiles are used, and whether the value is the middle of a deadband for on/off controls with hysteresis or the midpoint of a proportional control band. The following VAV reheat system rows from the table illustrate this:

<table>
<thead>
<tr>
<th>System category and configuration</th>
<th>Default setpoints (sp Occ, un-Occ)</th>
<th>Control strategy</th>
<th>Cooling airflow ON above</th>
<th>Cooling airflow control</th>
<th>Cooling coil ON above</th>
<th>Cooling coil SAT reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>07 VAV-reheat-Chiller-Boiler</td>
<td>75, 80</td>
<td>VAV airflow on at min in occ hours, cycles with cool in un-occ; airflow ramps up first with cooling demand, SAT then reset downward if needed.</td>
<td>always on 79 74 79 79 for vent (sp-1) (sp-1) (sp-1) no deadband mid of 2 °F ctrl band CP7 CP6 CP4</td>
<td>always on when there is airflow to maintain SAT mid of 2 °F ctrl band per zone-based reset CP7 was SP+2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For Cooling airflow, for example, the table indicates that...

- The on/off control schedule and setpoint are governed by HVAC profile CP7, which forces the airflow ON during all occupied hours and, depending upon the night/unoccupied control strategy selected by the user in System Schedules, cycles the airflow ON/OFF according to an elevated setpoint value that is 1 F below the Unoccupied Cooling Setpoint. Given the default Unoccupied Cooling Setpoint of 80 F and the selection of Temp setback with HVAC fan cycling as the Setback Strategy, the cooling airflow will be on at no less than the minimum fan flow rate when any one or more zones exceeds 79 F.
- The midband value and setback schedule for this value for proportional cooling airflow control at the VAV box is governed by HVAC profile CP4. This profile has a value 1 F below the Cooling Setpoint for both Occupied and Unoccupied hours. Thus, when the daytime or Occupied Cooling Setpoint is defaulted to 75 F, the proportional control of the zone airflow will use a midband of 74 F.

To reduce the offset of the daytime cooling airflow control with respect to the cooling setpoint, and thus reduce the standard throttling range so that the setpoints can be closer together without overlapping controls, the daytime value in profile CP4 needs to be closer to or even equal to the cooling setpoint.

- If you were to raise the daytime value in profile CP4 in the example above from 74 F to 75 F (equal to the cooling setpoint) without altering the default proportional control bandwidth of 2 F, this would also raise the lower end of the proportional control band by 1 F, thus allowing the heating and cooling setpoints to be 1 F closer together without overlapping controls.
- If you were to raise daytime value in profile CP4 by the same 1 F and also reduce the proportional control bandwidth from the default of 2 F to just 1 F, this would allow the heating and cooling setpoints to be 1.5 F closer together without overlapping controls.

<table>
<thead>
<tr>
<th>System category and configuration</th>
<th>Default setpoints (sp Occ, un-Occ)</th>
<th>Control strategy (default)</th>
<th>Heating airflow ON below</th>
<th>Heating airflow control</th>
<th>Heating coil ON below</th>
<th>Heating coil LAT control</th>
</tr>
</thead>
<tbody>
<tr>
<td>07 VAV-reheat-Chiller-Boiler</td>
<td>70, 60</td>
<td>VAV airflow on at min flow rate in occ hours, cycle on with heat in un-occ hours; coil-first, then add airflow when heat is required.</td>
<td>always on 62 69 59 for vent (sp+2) (sp-1) (sp-1) no deadband mid of 2 °F ctrl band HP5 HP6 HP1</td>
<td>always on to maintain (sp +1) (sp+1) minimum 55 °F SAT mid of 2 °F ctrl band HP4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If you then do the same for the Heating coil LAT control—moving the midband 1 F closer to the setpoint and contracting the proportional band from the default 2 F to just 1 F—you would gain the same 1.5 F of added leeway on the heating end of the control range. With both heating and cooling control bands moved and retracted by this same amount, you would free up 3 F of actual deadband (no control operation other than min airflow) between the setpoints.

If you then chose to have no actual deadband whatsoever, the modifications described above would permit heating and cooling setpoints separated by just 1 F without overlapping controls. Note, however, that this will tend toward instability as small variations in room temperature will very easily trigger alternating addition of cooling airflow and zone-level reheat. This will drive the model toward shorted simulation time steps, such as 1 to 6 minutes, to avoid modeling excessive energy consumption associated with oscillation between heating and cooling. And, very small simulation time steps will at significantly to the time required to perform an annual simulation. It is therefore highly recommended that for such models, if the project is anything much more than a very small building with very few zones, the majority of diagnostic simulation and testing of hypotheses, etc. should be performed using very short periods of 1 to 3 days in each relevant season—e.g., three very cold winter days, three very hot summer days, and three shoulder-season days.

For VE 2013, the user inputs for system setpoints and translation to controller inputs is being revised and will include separate heating and cooling user input parameters for Control Throttling Range. This will facilitate modeling unusually tight control of space temperatures without having to manually customize the HVAC profiles as described above.
Humidity control — dehumidification, sub-cooling, and reheat to SAT

When working with a humid climate, it’s important to understand that the pre-defined systems are set up so that any zone with excessive RH can vote for a cooler off-coil temperature (down to the user input for Cooling coil min LAT) to dry the air at the AHU. If the System AHU Heating coil LAT value is set lower than the Cooling coil min LAT, this will for immediate reheat at the AHU when, and only when, the cooling coil LAT is driven below the heating coil LAT by demand for dryer air.

- The controller MC2: Cooling SAT reset per zone dehumidification demand for each zone votes on the system AHU cooling coil LAT with respect to zone humidity, and the default setting is a 55% RH midband with 10% bandwidth, such that this controller will vote for the min cooling coil LAT if RH in the zone it is attached to gets up to 60% or higher. The Max. Percent Saturation (%), which is the top end of the zone RH control band, assuming a 10% bandwidth, is set in the Room Data or Thermal Template for each zone in the model (within Apache Thermal view) and this value is picked up by the Loads Data spreadsheet at the time of zone-level sizing. You can also adjust the RH midband value in the Loads data spreadsheet for the system or within the controller itself (if you do the latter, you might want to remove the “MC2:” from the controller reference name to avoid overwriting manual changes with subsequent updates from the spreadsheet.

- For cooling and dehumidification controls, it’s helpful to understand how the System Parameters inputs are used in the controls for cooling temperature reset and dehumidification at the AHU.

Example

- In the following example from the System side of the System Parameters dialog, the inputs are set so that:
  - AHU cooling coil LAT can be as low as 50 F for dehumidification purposes; however, the cooling coil LAT will be constrained to not less than the AHU Heating coil LAT when not driven to a lower value specifically for the purpose of dehumidification.
  - AHU heating coil LAT will be 54 F. Because this determines the minimum supply air temperature leaving the AHU, this sets the lower bound for the AHU cooling coil LAT, except when overridden for dehumidification, thus forcing immediate reheat at the AHU only when justified by need to dry the air. (This parameters should really come before the Cooling SAT reset in the dialog.)
  - Design cooling SAT for calculating zone airflows will be 55 F, and this independent of setting for coil LAT values, which can be lower if desired for dehumidification and/or cooling supply temperature allowing for heat pickup in the ductwork. In this example, setting this value at 55 F and the AHU Heating coil LAT to 54 F suggests that you anticipate at least 1 F temperature rise in the ducts when the AHU is at its minimum SAT. For this, ductwork heat pickup should be enabled by indicating (within the Ductwork Heat Pickup component on the system) an approximate duct U-value, surface area, and location (e.g., a return plenum zone) for the supply ducts. When duct heat gain/loss is not modeled, the Design Cooling SAT is normally set the same at the AHU Heating coil LAT, assuming this is the coldest air temperature that will ever be supplied to the zones.
  - The cooling SAT reset of 10 F will allow the SAT at the AHU to be raised up to 10 F above the Design value when all zones on the system are at or below the zone Cooling setpoint. In this example, this value would allow an SAT up to 64 F leaving the AHU. If the assumed minimum heat gain is present in ductwork, this would result in an SAT of 55 to 65 F at the zone terminal unit. (This parameters should really come last among these four in the dialog.)

These four parameters will be more logically arranged in a future version. A display-only filed will also be added to indicate the Min Cooling SAT from the AHU (uneditable) as the Min Cooling Coil LAT for zone cooling purposes that is coordinated with and thus determined by the AHU heating coil LAT.
A subsequent release will introduce revised means of translating system setpoints to controller inputs, and this will include user input parameters for control throttling range. This will facilitate modeling unusually tight control of space temperatures without having to manually customize the HVAC profiles.