PNNL-SA-183964

Re-tuning Measure Guide

Re-tuning Challenge Training Aid Providing Guidance for Re-tuning Implementation

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Re-tuning Measure Guide

This document provides guidance on the Re-tuning measures outlined in the Re-tuning Checklist. For each measure, the applicability, recommendation guidance, and validation steps (where applicable) are provided. Average savings estimates are also provided for each measure based on the GSA Portfolio and modeling completed by Pacific Northwest National Laboratory. Each building is unique and requires custom analysis to determine appropriate Re-tuning measures and control sequences. The intention of this guide is to provide information only. The reader must determine how the measures apply to their specific buildings.

"Turn-if-off" Measures

Reduce HVAC Schedules

Applicability

HVAC Equipment that is enabled via BAS schedule (e.g., Air Handling Unit (AHU), Dedicated Outdoor Air System (DOAS), Exhaust System)

This measure does not apply to:

- HVAC Equipment that is enabled via interlock command or demand sensing (e.g., hot water pump, chiller)

Guidance

- If Optimal Start is in place or is planned for implementation, start schedule 30 minutes prior to occupancy; end schedule at the end of occupancy.
- If Optimal Start is not in place and will not be used, start 1-2 hours prior to occupancy (some buildings may need longer).
- For DOAS systems, follow Optimal Start guidance. DOAS systems and exhaust systems should not be enabled after-hours or during start-up prior to occupancy.

Validation

- Use trend data to validate equipment shuts down overnight with existing or newly implemented schedules.
- Lack of (or poorly implemented) night setback may prevent equipment from shutting down.

Savings

- GSA Portfolio: 3.3% Average Savings Projection, 45% Prevalence of Opportunity (78 Buildings)
- 11.5% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 5.2% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Holiday Scheduling

Applicability

HVAC equipment that is enabled via BAS schedule (e.g., Air-handler, DOAS system, Exhaust System)

This measure does not apply to:

- HVAC equipment that is enabled via interlock command or demand sensing (e.g., hot water pump, chiller)

Guidance

- Check to see if federal holidays are programmed in the scheduler and if not, add applicable holidays.
- If the building operates 24/7 or does not otherwise change its operations on holidays, this measure can be disregarded.

Savings

- GSA Portfolio: 0.9% Average Savings Projection, 5% Prevalence of Opportunity
- 0.7% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Optimal Start

Applicability

Air Handlers

This measure does not apply to:

- BAS Systems without Optimal Start capabilities or with notoriously bad Optimal Start packages
- Some older control systems

Guidance

- Optimal Start is a pre-packaged program that uses zone temperatures and outdoor air temperatures to decide on the optimal AHU start time each morning through a machine learning algorithm.
- Add Optimal Start package to Air-handlers. Because the program learns and improves over time, implementing during mild weather is ideal.
- AHU Schedules must be revised to reflect the “latest start time” (30 minutes prior to occupancy) rather than the previous default start time that included morning warm-up/cool-down.
- Earliest start times should be set to the historical start time unless night setback is configured to be aggressive (tight setback values) which allows the earliest start time to be 1 or 2 hours earlier than previous default.

Validation

- Use trend data (AHU start/stop status timestamp) to validate that

    - AHUs start up at a different time each morning
    - AHUs start up near the latest start time during mild weather
    - AHUs rarely start up prior to the earliest start time
- Validate that most of the spaces are appropriately conditioned by the start of occupancy.

<u>Savings</u>

- Varies extensively based on baseline schedules.
- GSA Portfolio: 2.1% Average Savings Projection, 55% Prevalence of Opportunity
- 9.4% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 4.9% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Optimal Stop

<u>Applicability</u>

Air Handlers

This measure <u>does not</u> apply to:

- BAS Systems without Optimal Stop capabilities

<u>Guidance</u>

- Optimal Stop is a pre-packaged BAS program that shuts down AHUs prior to the scheduled stop time at a different time each day based on outdoor air temperatures and zone temperature drift patterns.
- It is also a self-tuning algorithm and improves as it learns the optimal start time.
- Best practice is to set the maximum early stop time to 30 minutes. In practice, this should shut fans down 30 minutes early on mild days and let zone temperatures "coast".
- On hot or cold days there should be very little change compared to the original schedules unless the zones are interior, or the building is very well insulated.

<u>Validation</u>

- Use trend data (AHU start/stop status timestamp) to validate that
    - AHUs stop at varying times, or stop consistently at the earliest shut-down time
- Validate that tenants are not complaining about the timing of shutdown, and perhaps inform them about this measure

<u>Savings</u>

- GSA Portfolio: 0.6% Average Savings Projection, 17% Prevalence of Opportunity
- 1.1% whole building energy savings – among 9 building types (Fernandez et al. 2017b)

Chiller Outdoor Air Enable

Applicability

Building with well-functioning economizing capabilities (air and/or water side)

This measure does not apply to:

- Buildings that use their main chillers for data center cooling
- Buildings without economizers or with inadequate or dysfunctional economizers

Guidance

- Determine the coldest required AHU supply air temperature when the outdoor air temperature is 55 to 60°F.
- Subtract 5 degrees from that temperature and use that as the outdoor air lockout temperature for the chillers.

Validation

- Validate that as the outdoor air temperature approaches the lockout setpoint, AHUs are still capable of meeting supply air temperature (SAT) setpoints.
- Chiller lockouts may uncover faulty economizers that require service or re-programming.
- Chiller lockouts may uncover faulty hot water coil valves in AHUs.
- Heating system OA lockouts can also help with this.
- Chiller lockouts that are set too low may result in chillers with frequent cycling of compressors or low Delta-T issues.

Savings

- GSA Portfolio: 0.7% Average Savings Projection, 12% Prevalence of Opportunity

Heating Outdoor Air Enable

Applicability

Building with well-functioning cooling coil valves (no substantial leaks)

This recommendation does not apply to:

- Variable Air Volume (VAV) Systems with high minimum airflow requirements (although this can be corrected via re-tuning)
- Certain buildings in very high humidity climates
- Hot water systems with di-electric unions

Guidance

- 60°F is usually a threshold above which well-functioning buildings can avoid using heating.
- Well-insulated or high interior load buildings may be able to push this down to 50°F or lower.

- If a lockout is not possible during occupied hours, consider a heating system lockout during unoccupied hours.
- If the building cannot lock out the heating system in the summer, prioritize hot water temperature reset.

Validation

- Validate in the summer that there are no cold spots. Identify the cause of the cold (usually minimum airflow) and correct.
- Heating lockouts may uncover faulty chilled water coil valves. Repair/replace leaking chilled water coil valves rather than removing lockout programming.

Savings

- GSA Portfolio: 2.6% Average Savings Projection, 28% Prevalence of Opportunity
- 2.6% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Keep AHUs off During Night Heating Cycles

Applicability

- **VAV systems with reheat and fan-powered boxes that have the ability to run on return or plenum air only**
- **Other VAV or constant air volume (CAV) systems with separate zone-level heating (e.g., baseboard heaters, fan coil units or induction units)**

Guidance

- Determine the strategy used for night setback thermostat maintenance in the winter. Many VAV systems are set up to run a heating night cycle using the main AHU supply fan.
- If the VAV boxes are all FPBs with reheat and can run on return or plenum air only, there is no reason for the AHU to come on at night. Revise the night cycle code to use only the fan-powered boxes and their reheat coils.
- Same guidance applies to perimeter units with heating capabilities (not connected to AHU). Revise the night cycle code to run only the perimeter units and not the main AHU at night.

Reduce Lighting Schedules

Applicability

Lighting controlled by BAS-schedules (sometimes this can also work with stand-alone lighting control)

This measure does not apply to:

- Manual lighting or occupancy sensor control

Guidance

- Determine reasons for any lighting schedules that extend beyond occupancy hours. Tighten any schedules that are unnecessarily loose.
- Reasons might include a few people who work late or an after-hours cleaning crew. An option in those cases is to implement night sweeps, where lighting circuits sweep off (generally every hour), unless occupants or cleaning crews hit a push-button reset of the lights. This helps keep the lighting on only where it is needed.

Savings

- GSA Portfolio: 1.6% Average Savings Projection, 15% Prevalence of Opportunity

Exterior Lighting-Schedule Off Late at Night

Applicability

Building with extensive exterior lighting, especially parking lot lighting, controlled by the BAS (usually also controlled by a photocell)

This measure does not apply to:

- Exterior lighting circuits that must be on throughout the entire night (e.g., for safety/security/crime) reasons

Guidance

- For some buildings, the parking lot lights may only be needed to accommodate employees entering or leaving the building.
- In these cases, there may be some period at night (i.e., midnight-4:00 a.m.) where the exterior lights can be scheduled off – overriding the photocell.

Savings

- GSA Portfolio: 0.2% Average Savings Projection, 3% Prevalence of Opportunity

De-lamping

Applicability

Over-lit spaces, especially corridors

This measure does not apply to:

- Spaces with aesthetic concerns around de-lamping

Guidance

- Get a hand-held light meter and during building tours, evaluate spaces that “feel” too bright.
- Prescribe a fraction of lamps to remove: $1 - \frac{Prescribed\ Lighting\ Level}{Actual\ Lighting\ Level}$
- Offices: 40 fc
- Conference Room: 30 fc
- Break Room: 15 fc
- Bathroom: 10 fc
- Corridors: 5 fc
- Labs: 50 fc
- Kitchens: 50 fc
- Dining Areas: 10 fc
- Warehouse/storage: 10 fc
- Garage: 2 fc

Snowmelt System Control

Applicability

Buildings with snowmelt systems

Guidance

- Snowmelt systems should be enabled based on both moisture sensing AND outdoor air temperature.
- Snowmelt systems should be disabled above 35°F OAT.

Savings

- GSA Portfolio: 2.3% Average Savings Projection, 6% Prevalence of Opportunity

Pump Shutdown When There is No Load

Applicability

Chilled or hot water systems with a building (usually secondary) loop pump that runs when the chillers or boilers are off

Guidance

- Determine from maintenance staff the reason for the building loop pump running continuously (freeze protection for coils?)
- If there is no legitimate reason, add programming to interlock the pumps with the on/off status of their associated boilers/chillers.

Savings

- GSA Portfolio: 0.5% Average Savings Projection, 9% Prevalence of Opportunity
- 0.1% whole building energy savings – among 9 building types (Fernandez et al. 2017b)

“Turn-it-down” Measures

Static Pressure (SP) Reset

Applicability

VAV Systems with duct static pressure setpoint control of supply fan VFD.

This measure is less applicable to:

- VAV boxes with pneumatic damper control

Guidance

- Best Practice: Program a reset of the duct static pressure setpoint based on zone-level feedback.
- Ideal feedback variable is VAV damper position.
- Other variables are occasionally used such as zone cooling demand.
- ASHRAE’s recommendation is a trim and respond algorithm that keeps the most open VAV box at 95% (*e.g., query VAV box damper positions, increase SP setpoint incrementally if max >95%, decrease if max <90%. Repeat every 5 minutes*)
- “Rogue Zones” can make the trim and respond strategy ineffective:
  - One undersized VAV box is always at 100% open
  - One or two zones have malfunctioning VAV dampers or malfunctioning airflow sensors and are always calling for additional cooling (damper is always at 100% open)
  - Bad thermostat location can drive this problem
- Options to handle “Rogue Zones” include:
  - Correct any physical faults causing Rogue Zones
  - Remove non-critical zones from algorithm (bathrooms, corridors, storage, etc.)
  - Control to the second (or in some cases third) most open damper instead of the most open
  - Switch to a linear reset based on average damper position

- Linear Reset:
  - If VAV minimum damper airflow rates (or minimum damper commands) are 0-10% of the maximums: Reset from minimum setpoint at 20% average damper command to maximum setpoint at 50% average damper command
  - Otherwise, reset from minimum setpoint at 30% average damper command to maximum setpoint at 60% average damper command
  - The above recommendations should only be used as a starting point
- Maximum Setpoint for Reset: Use current fixed setpoint unless there is evidence it is currently set too high or too low.
- Minimum Setpoint: 0.5 in. w.c. OR (if the current fixed setpoint is >1.5 in. w.c.) half of the maximum.
- Time-of-Day Reset
  - For AHUs with pneumatic VAV damper actuators or other systems without zone feedback.
  - Reduce static pressure setpoint to a lower value (1/2 to 2/3 of occupied value) during unoccupied hours.
  - If VAV systems are known to serve undersized VAV boxes (100% VFD speed is needed at all times), SP Reset may not be feasible.

<u>Validation</u>

- If SP reset is already in place, it should be evaluated for effectiveness
- Trend SP setpoint and actual supply fan SP
  - Does the actual static pressure follow the setpoint?
  - Does the setpoint reset downward effectively during part of the day?
  - If not, determine why not. Check for rogue zones and address as necessary.
  - Does the reset remain at its minimum setpoint most of the time? If so, tune reset to be more aggressive (lower minimum setpoint).
  - Is the feedback variable appropriate and does it appear to be working? If not, consider re-specifying the reset algorithm.

<u>Savings</u>

- GSA Portfolio: 2.0% Average Savings Projection, 74% Prevalence of Opportunity
- 1.4% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 1.1% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Static Pressure Reset for Dedicated Outdoor Air Systems (DOAS)

<u>Applicability</u>

DOAS with VFDs on the supply fans that are controlled to a static pressure setpoint

- This is usually the case if the air feeds into the outdoor air (OA) intake of AHUs. There will normally be a VAV box damper that regulates the flow of conditioned outdoor air from the DOAS into the AHU.

This measure <u>does not</u> apply to:

- DOAS with constant speed supply fans

Guidance

- Damper feedback can be used in an identical fashion to AHU static pressure reset with zone VAV boxes. Identical algorithms can be deployed.

Night Setback

Applicability

Zone Thermostats that take BAS setpoints

This measure does not apply to:

- Manual thermostats

Guidance

- Night Setback is critical in allowing fans to shutdown overnight and can be very effective at reducing annual heating energy consumption
- Use a differential of 2°F
- Option 1: Average zone temperature
  - Average temperature can mask cold zones; don't use too cold or too hot of a setback
  - 60-65°F recommended for heating setback
  - 80°F recommended for cooling setback
  - Choose only perimeter zones, if possible
- Option 2: Worst case zone temperature
  - 55-60°F recommended for heating setback (light construction should be lower, heavy higher)
  - 85°F recommended for cooling setback
- More aggressive night setback values may require earlier morning start-up times. Verify the current morning warm-up/cool-down effectiveness first.

Validation

Choose a week with cold temperatures

- For one AHU serving exterior zones, trend the zone temperatures for every thermostat served by the AHU as well as the fan status and heating coil control valve signal.
- Does the fan remain off until at least one zone thermostat drops below the night setback temperature? Note the time of night/morning the zone drops to the setback value and how often the AHU cycles on to maintain setback.
- If Optimal Start is not being used, make note of the time that the AHU enters normal operation and the time that the zone thermostats reach their occupied set points. How long does this process take on a cold morning?
- If Optimal Start is being used, check that most of the zones are arriving within 1-2°F of desired setpoints by 30 minutes prior to occupancy. If not, set the earliest start time to be earlier.

Savings

- GSA Portfolio: 3.4% Average Savings Projection, 26% Prevalence of Opportunity

Chilled Water Differential Pressure (DP) Reset

Applicability

Chilled water loops with variable speed building loop pumps controlled via a differential pressure sensor/setpoint.

Guidance

- Evaluate the current differential pressure setpoint.
    - Any value over 20 psi is suspiciously high and may lead to damaged valve seats. Choose 18 psi as the maximum setpoint.
    - If the chilled water system is active, the weather is warm or hot, and most cooling coil valves are open <20%, the setpoint is too high. Choose a value 2-4 psi lower than the current setpoint for the maximum setpoint.
    - Otherwise, choose the current setpoint as the maximum setpoint.
- A linear reset based on average chilled water coil valve command is recommended with the range as follows:
    - Maximum DP setpoint at 50% average chilled water coil valve command (or 90% maximum command)
    - Minimum DP setpoint at 25% average chilled water coil valve command (or 45% maximum command)

Savings

- GSA Portfolio: 0.5% Average Savings Projection, 33% Prevalence of Opportunity
- 0.2% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 0.13% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Hot Water Differential Pressure Reset

Applicability

Variable speed building loop hot water pumps

This measure does not apply to:

- Buildings with a large number of reheat or other hot water coils
- Hot water pumps that are small <5-10 HP (not economical)

Guidance

- A direct analogue to Chilled Water DP Reset. The typical approach is to use the average hot water coil valve position to reset the differential pressure setpoint. The same setpoints are applicable.
- The challenge comes with typically high numbers of hot water coils.

- Work-around: Use a small sample (20-30 hot water coil valves in the average), instead of all of the hot water coil valves
- Alternative: Reset using outdoor air temperature (OAT) and time of day: Example
  - Occupied Hours: Reset from 7 psi @ 50°F to 15 psi @ 20°F
  - Unoccupied Hours: Reset from 7 psi @40°F to 12 psi @ 10°F

Savings

- GSA Portfolio: 0.2% Average Savings Projection, 26% Prevalence of Opportunity
- Less than 0.1% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- Modeling shows electricity savings means less waste heat delivered to water flowing through pump (boilers must work slightly harder to maintain water temperature setpoint)

Chilled Water Supply Temperature (CHWST) Reset

Applicability

Centrifugal or Scroll chillers

This measure does not apply to:

- Buildings with frequent trouble meeting cool AHU supply air temperature setpoints
- Buildings with issues of secondary chilled water loop "overflowing" primary loop which can lead to higher building chilled water supply temperatures (i.e., 48°F when 42°F is generated at the chillers)

Guidance

- An "optimization" measure. See Figure 1.
- Saves electricity by increasing chilled water temperature and thus lowering the chiller's compressor pressure "lift"
- May increase electricity by increasing the volume of chilled water required to meet the building cooling loads (increased pump power).
- Recommended approach:
  - Reset chilled water temperature based on average chilled water coil valve position:
  - Example: Reset from 42°F at 60% average valve position to 48°F at 30% average valve position

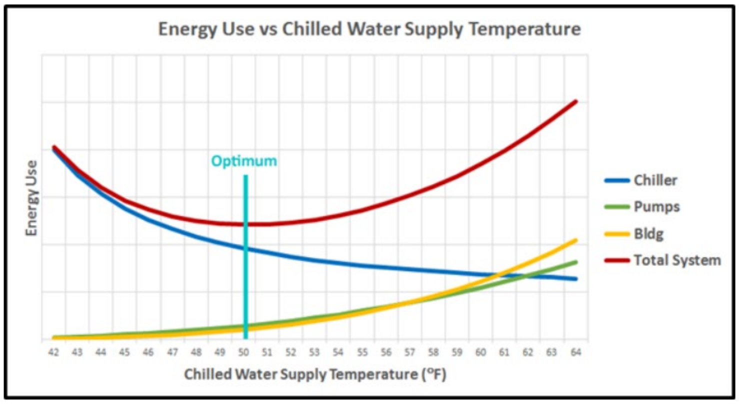

Figure 1. Energy use vs. chilled water supply temperature

<u>Savings</u>

- GSA Portfolio: 0.7% Average Savings Projection, 41% Prevalence of Opportunity
- 0.3% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 0.1% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Hot Water Supply Temperature (HWST) Reset

<u>Applicability</u>

- **Buildings with Condensing Boilers**
- **Buildings with a Secondary Hot Water Loop with an independent supply setpoint**

This measure <u>is less applicable</u> to:

- Buildings with conventional boilers and a single hot water loop

<u>Guidance</u>

- For condensing boilers, saves energy by taking advantage of much greater efficiencies at low hot water temperatures, but the reset should feature low-end setpoints below 120°F and ideally, closer to 100°F.
- For buildings without condensing boilers, saves energy through reduced convective heat losses from pipes, fittings, and other hot water loop components, especially as they transverse mechanical rooms, chases, plenums, and other unconditioned spaces
- Each building is fairly unique in terms of what range of temperatures will work.
- Outdoor air temperature-based resets are common and appropriate.
- "Scheduled" setpoint reductions at night (automatically reduce the calculated setpoint by 20°F during nights and weekends) but restore the normal setpoint by 2 a.m. for the morning warmup cycle.
- There should be about a 1°F to 1°F correspondence between outdoor air temperature and the required hot water temperature for proper conditioning.

    Example:

    - Condensing Boilers: Reset from 100°F setpoint at 50°F OAT to 150°F setpoint at 0°F OAT
    - Conventional Boiler/Secondary HW Loop: Reset from 120°F setpoint at 50°F OAT to 170°F setpoint at 0°F OAT
    - Conventional Boiler/Single HW Loop: Reset from 150°F setpoint at 30°F OAT to 180°F setpoint at 0°F OAT

<u>Validation</u>

- Validate via trend data that the hot water temperature reaches its maximum temperature at the corresponding minimum OA temperature, and its minimum temperature at the corresponding maximum OA temperature
- If the temperature of the hot water loop is greater than 5°F above or below the set point at the minimum or maximum OA, investigate to determine the cause.
- Verify that during very cold weather, there are no exterior zones struggling to meet their heating set points. If so, adjust the maximum.

<u>Savings</u>

- GSA Portfolio: 1.2% Average Savings Projection, 42% Prevalence of Opportunity
- Conventional Boilers: 0.5% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- *Mix of Conventional and Condensing Boilers:* 1.5% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Condenser Water Temperature Reset

<u>Applicability</u>

Variable speed cooling towers (with condenser water temperature setpoint)

<u>Guidance</u>

- An “optimization” measure.
- Saves electricity by decreasing condenser water inlet temperature and thus lowering the chiller’s compressor pressure “lift”
- Increases electricity by increasing the cooling tower fan speed to do so.
- Best practice is to reset based on outdoor wet bulb temperature (OAWBT) plus an approach temperature.
- Choice of the proper approach temperature may vary based on the chillers
    - As low as OAWBT+5°F for modern, efficient chillers
    - As high as OAWBT+12°F for e.g., undersized towers
- Smart strategies should focus on lowering condenser water temperature without approaching the very upper end of the cooling tower’s fan power curve
- Add minimum and maximum limits based on chiller vendor specifications
- Calibrated and properly located OA dry bulb and OA relative humidity sensors are critical

<u>Savings</u>

- GSA Portfolio: 0.5% Average Savings Projection, 36% Prevalence of Opportunity

- 0.2% whole building energy savings – among 9 building types (Fernandez et al. 2017b)
- 0.6% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Chiller Staging

Applicability

- **Multiple chiller systems**
- **Variable speed chillers**
- **Centrifugal chillers**

Guidance

- The chiller system can be roughly optimized through staging strategies.
- If staging on an additional chiller entails staging on an additional condenser water pump, chillers should run to, at or near, 100% of their capacity before staging on another chiller.
- Otherwise, there may be a benefit to staging up significantly before a chiller reaches 100% of its capacity.
- The stage up point depends somewhat on the chiller, but also on the specific operating conditions. If chillers are staged up too early during high lift conditions, it would put the chillers into surge conditions. To compensate, the chillers will throttle inlet guide vanes to control capacity, reducing efficiency.
- See research from Steven A. Taylor (Figure 2) (Taylor 2012)
- Two-chiller systems: Calculate "staging" part load ratio (SPLR) using CHWST and condenser water return temperature (CWRT) using Equation (1):

$$SPLR = 0.009 \times (CWRT - CHWST) + 0.21 \quad (1)$$

Example: 2 x 500 Ton Chillers (1,000-ton total), CWRT-CHWST = 20°F

1. Calculate SPLR = 0.39
2. Stage-up from 1 to 2 chillers when total load > 390 tons (or % speed on Chiller 1 is >78%)
3. Stage-down from 2 to 1 chiller when total load < 360 tons (or % speed on both chillers is < 36%)
4. Also include a time delay that forces that staging switch to remain active for at least 30 minutes before staging back up or down.

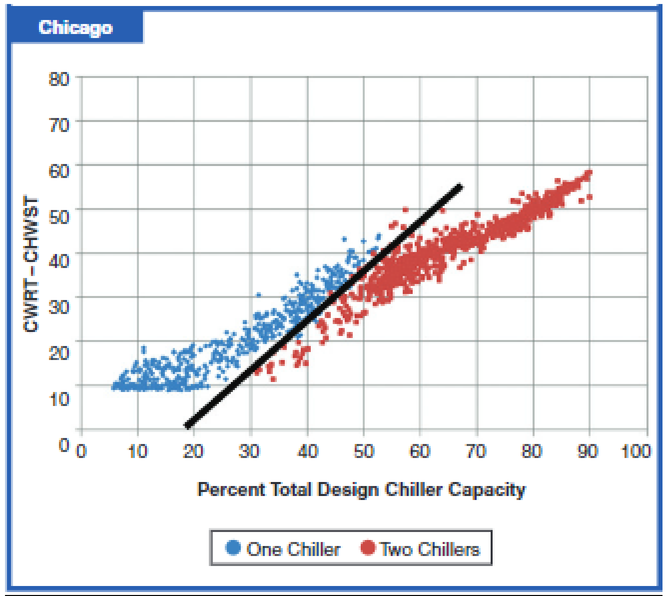

Figure 2. Optimum staging vs. (CWRT-CHWST) and plant part load ratio Chicago (Taylor 2012)

Savings

- GSA Portfolio: 0.9% Average Savings Projection, 14% Prevalence of Opportunity

AHU Freeze Protection

Applicability

Buildings in cold winter climates that use nighttime freeze protection (for the cooling coil) with the AHU heating coil. This form of control often involves running the heating coil valve wild (100%).

Guidance

- This strategy has been observed to “cook” the air-handler overnight. Mixed and supply air temperature sensors can read 100-150°F. Obviously overkill and a waste of heating.
- This strategy may also cause the hot water pump to run harder than necessary if enough heating coils are involved.
- Instead, add a layer of programming that controls the heating coil valve at night to maintain a mixed air temperature of 60°F.
- Make sure the programming is only in place when there is an actual danger of coil freeze. For some buildings, this may by 30°F, for some it may be 10 or 20°F.

"Mitigate Simultaneous Heating and Cooling" Measures

Discharge Air Temperature (DAT) Reset

Applicability

VAV Air-Handling Units and Multi-Zone Constant Volume Systems

This measure does not apply to:

- Single-Zone Constant Volume Systems

Guidance

Goals:

- During cold weather, increase the discharge air temperature as much as possible without driving a significant number of boxes into cooling mode. (Avoids use of zone-level heating. Warmer DAT temperature is brought about generally through more return air, rather than mechanical heating.)
- During warm weather, decrease the discharge air temperature as much as possible without driving a significant number of boxes into heating mode. (Cooling can still be performed with somewhat warmer discharge air, but more air must be delivered, increasing fan power.)

Feedback Variables:

- ***Zone Heating Demand*** (usually scaled 0-100 number) or ***Count of Zones in Heating Mode***
    - Example: Reset SAT from 63°F @ 5% average heating demand to 70°F at 50% average heating demand.
    - Much better choice but doesn't give you information about when the supply air temperature has been raised too far (leading more zones into cooling mode).
- ***Zone Cooling Demand*** (usually scaled 0-100 number) or ***Count of Zones in Cooling Mode***
    - Example: Reset SAT from 55°F @ 60% average cooling demand to 62° F at 10% average cooling demand.
    - A good choice but doesn't give you information about when the supply air temperature has been lowered too far (leading more zones into heating mode).
- Best to integrate both if possible. For example: ***Avg. Zone Heating Demand Minus Avg. Zone Cooling Demand*** or ***Count of Zones in Cooling Minus Count of Zones in Heating (Highest Demand Wins)***.
- ***Supply Fan Speed* or *Average VAV Damper Position***
    - The idea here is to take advantage of VAV systems where zone airflow demands decrease to a minimum in heating mode and ramp up to a maximum in cooling mode.
    - Can be a useful choice if that is the case, but you need to make sure the VAV box airflow response does not increase zone airflow based on heating demand (above a minimum for satisfied boxes). The VAV airflow response to zone temperature needs to look like the plot below on the left, not the right (see Figure 3).

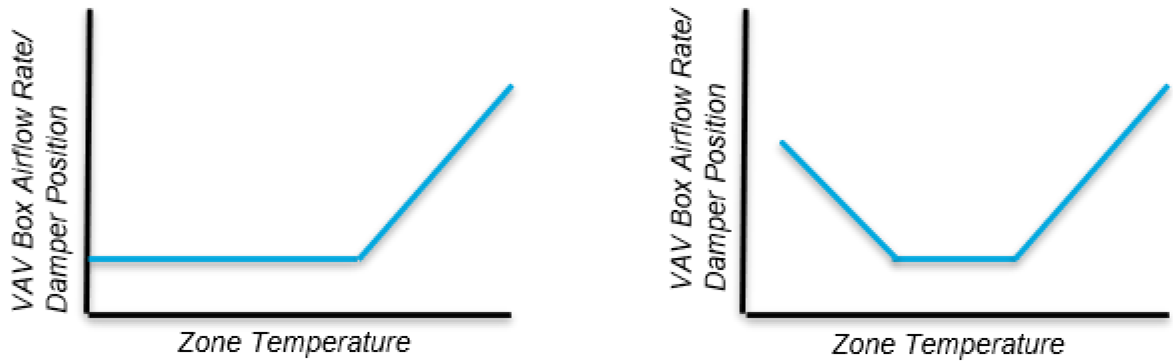

Figure 3. VAV box airflow control strategies; single maximum on the left, dual maximum on the right.

- ***Average VAV Damper Position*** can conflict with static pressure reset algorithms that use the same feedback variable. If this is the case, one reset needs to take priority as a “Stage 1 response.”
- ***Outdoor Air Temperature***: Simple solution, easy to implement. Modeling shows that this may only capture ½ the savings compared to a zone feedback approach.
- ***Return Air Temperature***: Commonly found. Attractive feedback variable because it aggregates the zones into a single feedback variable. Thus, still easy to implement, but with major concerns and pitfalls
    - Minimum and maximum return air temperature limits are often chosen arbitrarily.
    - What if zones maintain the same temperature or near the same temperature setpoint year-round? Return air temperature tells you nothing.
    - Return air feedback only appropriate if effective zone heating setpoints and cooling setpoints have substantial variation (at least 3-4°F dead band).
    - Minimum and maximum return air temperatures should be roughly tied to the average zone heating and cooling setpoints respectively, but they need to take into account return air heat gain, for example, off of lighting fixtures or air stratification from zone heating sources.
    - Example: In the winter, most zones are in heating mode and maintaining thermostat setpoints of 71°F however the return air temperature reads 73°F. In the summer, most zones are in cooling mode and maintaining thermostat setpoints of 75°F, however the return air temperature reads 77°F.

Setpoints and ranges:

- For AHUs whose discharge air serves a cooling function with zone-level reheat, 55°F (minimum) to 65°F (maximum) is usually a good range
- Increase maximum to 70°F if there is a history of needing temperatures that high, or if zones are still predominately in heating mode at 65°F
- Reduce the minimum to 53°F in humid climates for extra dehumidification
- See Steven Taylor’s recommended algorithm in Figure 4.

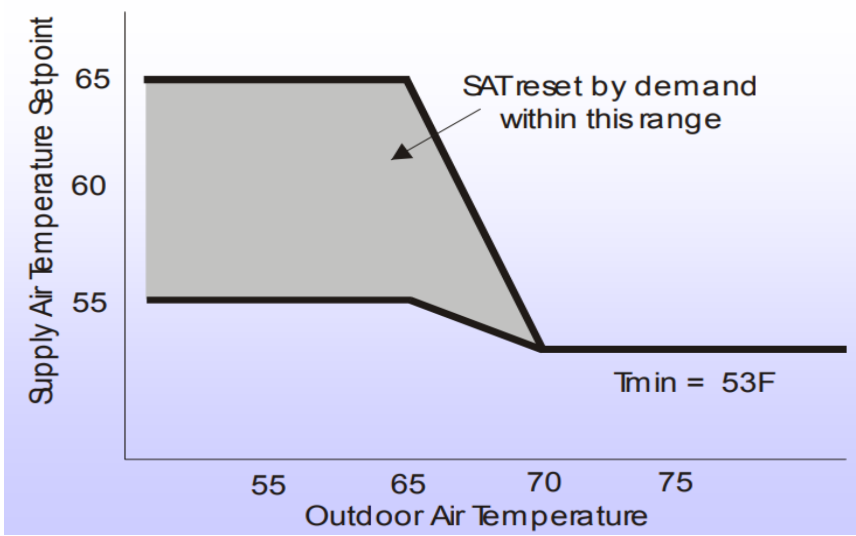

Figure 4. SAT Reset in VAV Systems based on Zone Demand (Taylor and Seidl 2008)

<u>Validation</u>

- Validate through trending or BAS spot-checking that the AHU is meeting its DAT setpoints. Any AHUs that remain significantly above or below setpoint should be evaluated for faulty/leaking coil valves or potential PID controller problems.
- After reset changes are implemented, validate via interval metered data analysis that building electricity consumption is not increasing during occupied hours. If so, determine if the DAT setpoints are significantly higher than before. This may be an indication that the DATs are too high and causing excess fan power.
- Validate via trending during cold weather that the DAT consistently resets to 60°F or higher. If not true determine the lower DATs are justified, given space loads.

<u>Savings</u>

- GSA Portfolio: 2.0% Average Savings Projection, 74% Prevalence of Opportunity
- Outdoor air temperature-based reset. Baseline was constant 55°F setpoint: 1.3% to 7.0% depending on building type (Fernandez et al. 2017b)
- Demand-based reset. Baselines included a mix of constant 55°F setpoint and seasonal setpoint change from 55 to 60°F: 10.0% whole building energy savings – among 3 building types (Taasevigen et al. 2019)
- Savings primarily on heating. Savings is strongly influenced by baseline control and climate.

Reduce VAV Box Minimum Airflow Setpoints

Applicability

- **VAV Boxes with Minimum Airflow Setpoints**
- **VAV Boxes with Minimum Damper Commands**

This measure does not apply to:

- Constant Volume Systems

Guidance

- Minimum VAV airflow setpoints are ostensibly about ensuring adequate zone ventilation at all times.
- Minimum airflow setpoints are generally determined based on design occupancy assumptions, meaning zones can end up being over ventilated for significant periods of the time.
- When zones become heavily occupied, internal heat loads rise, leading VAV boxes to go into cooling mode, which drives up airflow, providing increased ventilation.
- In addition, air mixes extensively throughout buildings. Ventilation can be trusted to be metered at the OA damper and not over-policed at the zone level.
- Minimum VAV airflow setpoints create excess energy consumption in two ways
- They can force zones to accept a greater amount of relatively cool supply air than is required for zone conditioning. To compensate, the VAV box reheat coil will activate. This can even occur in the summer for some zones (and is the leading cause of summer gas/steam use in buildings with VAV systems).
- By limiting certain zones to a higher-than-required minimum airflow rate, the total amount of air that must be delivered throughout the system is increased, increasing fan power consumption.
- Limit minimum airflow rates to 10%-15% of each VAV box's maximum airflow rate.
- For zones with very erratic occupancy and/or critical ventilation concerns, choose 25% minimum airflow rate.
- For zones that are not continuously occupied (corridors, storage areas, etc.), set minimum airflow rates to 0%.
- For VAV boxes without airflow sensors, use the same percentages above for minimum VAV damper commands.
- Setpoint changes made via the BAS should include updates to the default values held in the controllers.

Savings

- GSA Portfolio: 3.4% Average Savings Projection, 37% Prevalence of Opportunity
- 40% Baseline minimum airflow rates, reduced to 25%: 4.9% to 16.1% whole building energy savings depending on building type (Fernandez et al. 2017b)
- 35 to 40% Baseline minimum airflow rates, reduced to either 20% or 10%: 9.3% whole building energy savings – among 3 building types (Taasevigen et al. 2019)
- Targets most of the same "pot of savings" as Discharge Air Temperature Reset

Enable/Fix Airside Economizers

Applicability

AHUs and RTUs with Airside Economizers

Guidance

- Economizers are often found not working properly
- Sometimes there are control/BAS limitations such as
    - Inappropriately low maximum dry bulb economizer limits (e.g., 55 to 60°F)
        - This can be a response to concerns about introducing humid outdoor air (e.g., when it's raining). Propose differential enthalpy control as a solution.
    - Inappropriately high minimum dry bulb economizer limits (e.g., >45°F)
        - Even at cool outdoor air temperatures, economizers are still critical in meeting supply air temperature setpoints without resorting to mechanical cooling. Lower setpoint to 35-40°F.
    - Economizer inappropriately locked out via programming for no good reason
- In most cases, recommend switching from fixed dry bulb to differential dry bulb (dry climates) or differential enthalpy (humid climates)
- AHUs using fixed OA volume control for ventilation designs often over-ventilate and are found to be "economizing" (introducing more OA) when not needed

Validation

- Trend the outdoor air temperature (OAT) and return air temperature (RAT) (or OA/RA enthalpy), mixed air temperature (MAT) and outdoor air damper (OAD) commands for a sample of AHUs.
- When the OAT is less than the RAT (by more than 2°F) or the outdoor-air enthalpy is less than the return enthalpy by more than 1 Btu/lb), make sure that the OAD is opening beyond the minimum position to maintain the AHU DAT set point via the MAT.
- A good practice is to configure the economizer to control the OA Damper to maintain the MAT at the DAT Setpoint – 2°F.
- Use weather underground history (https://www.wunderground.com) to validate that OAT and outdoor relative humidity (OARH) used for economizer control matches reasonably with nearby weather stations. Consider recommending switching to local weather station rather than onsite sensor.

Savings

- GSA Portfolio: 1.0% Average Savings Projection, 31% Prevalence of Opportunity
- Baselines with economizers fully locked out: 3.5% whole building energy savings – among 5 building types (Taasevigen et al. 2019)
- Baselines with 65°F maximum dry bulb limits: 0.1% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

Thermostat Setpoints and Dead bands

Guidance

- Scenario 1: Single Thermostat Setpoint
    - Make sure that there is no way for the zone to alternate from a heating to a cooling response and vice versa. Consult trend data if necessary.
        - In heating mode, the zone should operate with constant airflow/damper positions and modulate zone heating to satisfy setpoint.
        - In cooling mode, the zone should have any heating equipment locked out and rely on changes in airflow to maintain setpoint.
    - Make sure that the single setpoint is seasonally adjusted higher in the summer and lower in the winter. For desk work, recommend 70°F (winter) and 74°F (summer).
- Scenario 2: Dual Thermostat Setpoint with Dead Band
    - Entails an effective heating setpoint that is lower than an effective cooling setpoint by a dead band. Usually the setpoints remain constant year-round, with the lower setpoint serving as a winter/heating setpoint and the higher setpoint as a summer/cooling setpoint.
    - Common with VAV, fan coils and similar systems, the dead band, if wide enough, ensures that there is not an alternating heating/cooling response, and creates a “satisfied” zone where airflow setpoints/damper commands back off.
    - Make sure that thermostat dead bands are at least 3°F (preferably 4°F).
    - Some BAS allow the heating and cooling setpoint values to be reversed so that the HVAC system is “confused” and simultaneously heating and cooling.

Validation

- Trend zone thermostat temperature, zone damper command, and zone heating valve command for a few key/sample zones. Validate that there is no alternation between heating and cooling modes of operation.
- For dual setpoint systems, scrutinize zone temperatures in relation to their dead bands. Zones well within their dead band temperature range should have their airflow setpoint or damper command set to the VAV box’s minimum setpoint. If not, troubleshoot to determine why, and consider recommending alternative VAV box programming.

Savings

- GSA Portfolio: 1.7% Average Savings Projection, 37% Prevalence of Opportunity

Eliminate Fighting Thermostats

Guidance

- Scrutinize thermostat setpoints across the floors (e.g., through floor temperature graphics on the BAS).
- Setpoints should be fairly consistent. Some variation is acceptable to account for different occupant preferences, however wildly different setpoints among adjacent zones (difference is close to or greater than the dead band range) will cause simultaneous heating and cooling within the floor.

- Evaluate data centers with multiple CRAC units for this problem
    - Thermostat setpoints should be identical between units.
    - Many CRAC units have hot water or electric heating coils and an associated heating temperature setpoint. These heaters are counterproductive at best and should be locked out.
    - Simultaneous humidification and dehumidification have been observed. Make sure humidification/dehumidification setpoints are also identical between units and are configured to be no closer than 30% RH to each other.

<u>Savings</u>

- GSA Portfolio: 0.6% Average Savings Projection, 6% Prevalence of Opportunity

DOAS: SAT Reset and Heat Recovery Control

<u>Applicability</u>

- **Dedicated Outdoor Air Systems**
    - **Direct-to-Zone Air Delivery**
    - **Supply Air Delivery to AHU Outdoor Air Intake**

<u>Guidance</u>

In general, aim to lock out heat recovery when it is appropriate to economize.

1) Direct-to-Zone Delivery, No Heat Recovery
    - Create a range of outdoor air temperatures with no conditioning (i.e., 52-70°F).
    - Above this range in humid climates, use the DOAS as the primary engine for dehumidification. Set DOAS supply air temperature to 52-53°F and relax supply air temperature on other AHUs to 55°F if possible.
    - In dry climates, set DOAS supply temperature to 60-65°F and allow AHUs to be primarily responsible for cooling.
    - Below the "no conditioning" range, set a low outdoor air temperature DOAS supply air temperature of between 55°F (heavy occupancy) and 65°F (light occupancy).
    - Make sure minimum airflow setpoints or minimum damper commands from VAV systems are set to 0 (or 10% of maximum for pressure dependent VAV boxes).
2) Direct-to-Zone Delivery, Heat Recovery
    - Lock out heat recovery coil in "economizer range" of 55-70°F
    - OR, in that economizing range, set the DOAS supply air temperature equal to the outdoor air temperature plus supply fan temperature rise (SAT control will modulate the heat recovery to an intermediate speed for some systems).
    - Above economizer range, enable heat recovery and set the DOAS supply air temperature to 53°F (humid climates) or 55-60°F (dry climates).
    - Below economizer range, enable heat recovery and set the DOAS supply air temperature to 65°F.
    - Ensure that minimum airflow setpoints or minimum damper commands from VAV systems are set to 0 (or 10% of maximum for pressure dependent VAV boxes).
3) DOAS→ AHU Outdoor Air Intake, with or without heat recovery

- Systems typically sized to provide maximum of around 20-30% outdoor air in aggregate to AHUs.
- In choosing DOAS supply air temperatures, work backwards from required AHU supply air temperature, accounting for the mixing of return air with conditioned outdoor air.
- For example, if during cool weather AHUs have 65°F SAT setpoints, return air temperatures are 72°F and DOASs provide 25% OA on aggregate, 44°F DOAS supply air temperature would be ideal for avoiding use of mechanical heating and cooling. Aim to use proper DOAS SAT setpoints to avoid use of waterside economizers, if possible.
- Example DOAS SAT Reset: Reset from 45°F DOAS SAT at 45°F OAT to 55°F SAT at 55°F OAT. (Fernandez et al. 2017a)
  - Figure 5 shows AHU cooling coil valve positions with the AHUs supplied by a DOAS on a 10°F day, with a 55°F DOAS SAT setpoint.
  - In this case a reduction in setpoint to 45°F may have mitigated or eliminated the need for additional cooling.

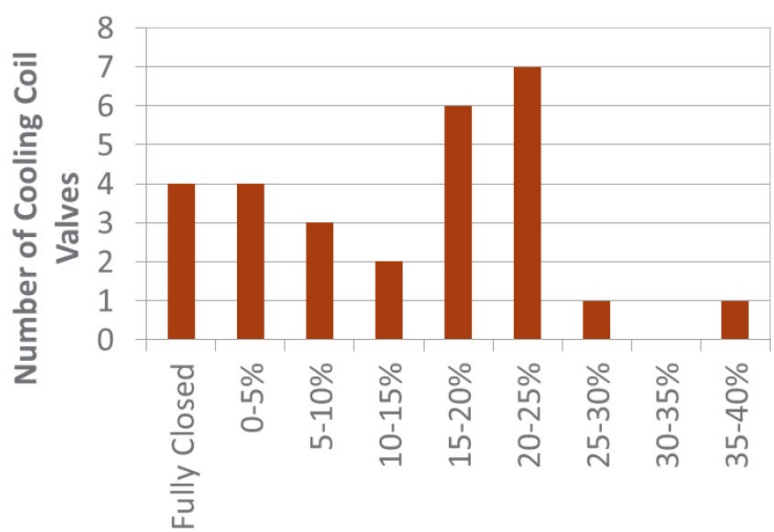

Figure 5. AHU cooling coil valves through the building on a cold (10°F) day

4) DOAS with sensible AND enthalpy wheels and conditioning in-between
   - Note in Figure 6 that the sensible wheel “robs” the supply air stream of its generated cooling
   - Analytic findings: Minimize heating and cooling coil for 65°F SAT setpoint by
     - Using both wheels below 35°F OAT
     - Using only the enthalpy wheel between 35°F and 60°F and above 75°F OA
     - Keeping both wheels off between 60°F and 75°F OAT

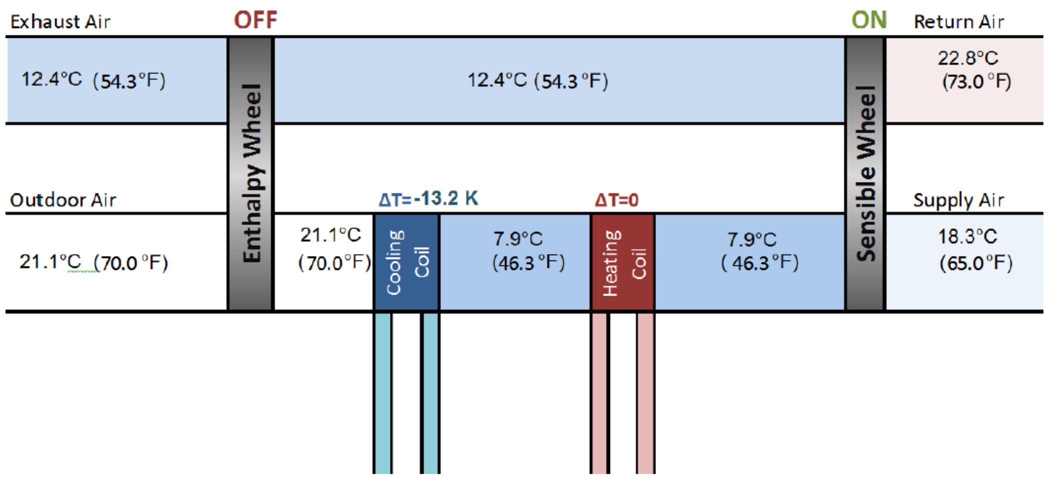

Figure 6. DOAS example with sensible and enthalpy wheels

Savings

DOAS Supply Air Temperature Reset

- GSA Portfolio: 1.9% Average Savings Projection, 18% Prevalence of Opportunity
- 1.6% whole building energy savings – among 5 building types (Taasevigen et al. 2019)

DOAS Heat Recovery Control

- GSA Portfolio: 1.5% Average Savings Projection, 6% Prevalence of Opportunity

Night Purge

Applicability

- **Dry/desert climates with frequent warm days and cool/dry nights**
- **Variable speed air systems**
- **Full air-side economizing; functional economizers**
- **Building has extended morning cool-down cycles (>2 hours prior to occupancy)**
- **AHU has Optimal Start in place or will implement Optimal Start alongside this measure**

Guidance

Sample Algorithm:

- If outdoor air temperature is less than 65°F (adjustable) AND average zone temperature for AHU system is more than 1°F above occupied cooling setpoint AND time is after midnight and prior to Optimal Start latest start time THEN
    1. Lock out AHU heating and cooling coil AND boilers.
    2. Turn on supply fan, limit fan VFD speed to 50%.

3. Lock outdoor air damper to 100%.
4. Operate this night purge cycle until the average zone temperature is 1°F below occupied cooling setpoint.

Savings

- GSA Portfolio: 0.3% Average Savings Projection, 3% Prevalence of Opportunity

“Reduce Outdoor Air and Infiltration” Measures

Demand Control Ventilation (DCV)

Applicability

- **Reliable return air or floor CO_2 sensors**
- **Fully modulating economizers**

Guidance

- DCV uses feedback from indoor air quality sensors to determine the ventilation rate or outdoor air damper position.
- As often conceived, DCV does not save energy. Why? It is often set up only to increase the ventilation rate above the normal baseline during times of under-ventilation and not vice versa.
- When implementing, make a corresponding lowering of baseline outdoor air damper commands or airflow setpoints.
- Has the potential to save a lot of energy in cold climates, and a moderate amount of energy in hot climates, but not very much in mild/marine climates.
- CO_2 sensors can be notoriously faulty. Implement a fault tolerant strategy. Don’t implement a strategy that would drive the outdoor air dampers to 100% indefinitely.
- Ambient CO_2 concentration is around 400 ppm
    - Re-calibrate or replace first any CO_2 sensor reading below 400 ppm.
- Best practice is to avoid CO_2 concentrations more than 700 ppm above ambient (1,100 ppm)
- Example 1: Baseline OA damper command of 20%.
    - DCV strategy: Reset from 10% OA damper command at 800 ppm to 30% OA damper command at 1,100 ppm
- Example 2: Baseline OA flow rate setpoint of 5,000 cfm
    - DCV strategy: Reset from 2,500 cfm setpoint at 800 ppm to 7,500 cfm at 1,100 ppm

Savings

- GSA Portfolio: 1.1% Average Savings Projection, 18% Prevalence of Opportunity
- 3.3% whole building energy savings – among 3 building types (Taasevigen et al. 2019)

Reduce Minimum Outdoor Air

Applicability

AHUs with modulating outdoor air dampers

This measure does not apply to:

- AHUs with only full open/shut minimum outdoor air dampers (usually paired with separate economizer dampers)
- Buildings with excess exhaust air that needs balancing
- Buildings/AHUs otherwise suitable for DCV

Guidance

- Determine rough compliance with ASHRAE 62.1 and reduce any excess default ventilation rates. Many operational sequences are based on unrealistic design occupancy
- Office and most commercial spaces: 5 cfm/person + 0.06 cfm/ft^2
- Consult with the building management and O&M staff. What is the worst-case occupancy based on experience?
- If AHUs do not have outdoor airflow sensors, rely on the following heuristics:
    - In office settings, VAV AHUs typically deliver about 0.6 cfm/ft^2 of supply air
    - The outdoor air fraction can either be calculated as $OAF = \frac{MAT-RAT}{OAT-RAT}$ or the outdoor air fraction can be approximated as equal to the damper command.
- For each AHU, calculate the outdoor airflow rate, and totalize at the building level. Compare to prescribed amount from ASHRAE. Reduce airflow setpoints or outdoor air damper commands proportionally.

Savings

- GSA Portfolio: 2.4% Average Savings Projection, 12% Prevalence of Opportunity
- 3.3% whole building energy savings – among 3 building types (Taasevigen et al. 2019)

Building Pressure Control

Applicability

- **Building Static Pressure Sensors**
- **AHU Return Air Fans**

This measure is less applicable to:

- High rises (stack effect can make effective pressure control elusive)

This measure does not apply to:

- Buildings with excessive exhaust requirements

Guidance

- Proper pressure control balances building exhaust air sources (AHU relief air, dedicated exhaust fans) with outdoor air intake (DOAS, minimum outdoor air and economizer dampers, makeup air units).
- Excessive negative pressurization can pull outdoor air in through the envelope (poorly sealed doors and windows, rooftop penetrations, unused or improperly pressurized HVAC systems). This tends to cool (in the winter) spaces that need to be directly heated. When the air is brought in via outdoor air intakes (economizers or DOAS systems), some or all the cool air can be used productively to temper warm return air and meet SAT setpoints.
- Excessive positive pressurization makes AHU fans work harder to push ventilation air into the building.
- The goal is a neutral to slightly positive pressure (0 to 0.05 in. w.c. static pressure)

<u>Approaches</u>

- Manual, iterative approach
    - Make note of pressurization at entrance doors (dollar bill test).
    - If air is entering the building without wind assistance, reduce AHU return fan offsets by 10-20% and re-test. Continue until neutral pressurization is achieved.
- Building pressure sensor feedback
    - Example: reset from -40% return fan offset (relative to supply fan VFD speed) at -0.1 in. w.c. (building or floor static pressure sensor) to 0% return fan offset at 0.05 in. w.c.
- Inventory approach (appropriate for airflow setpoint control of supplies and exhausts)
    - Inventory all exhaust sources that are ON regularly during occupied hours AND pull air from the body of the building (rather than a garage or other isolated space). Shut off or reduce speed on any unnecessary dedicated exhaust fans.
    - Inventory all outdoor air intake sources that deliver air to the body of the building.
    - Create a dynamic BAS summation that tracks outdoor air intake CFMs and exhaust CFMs, multiplied by a 1 or 0 based on their on/off status. For constant speed systems, assume their originally specified constant flow rate is accurate.
    - Create a reset that modulates tunable (those under the influence of variable speed fans or dampers) exhaust cfm setpoints such that the supply cfm remains above the return cfm.
        - Example: Calculate ∆CFM = intake CFMs- exhaust CFMs
        - Use trim and respond logic:
            - If ∆CFM is negative, subtract 100 CFMs from all tunable exhaust setpoints
            - If ∆CFM is more than 3,000, Add 100 CFMs to all tunable exhaust setpoints
    - Airflow sensors can be very poorly calibrated. This is not a fault-tolerant approach.

<u>Savings</u>

- GSA Portfolio: 1.4% Average Savings Projection, 24% Prevalence of Opportunity

Close OA Dampers at Night/Weekends/Start-up

Applicability

AHUs or RTUs with outdoor air intakes (either minimum outdoor air dampers or economizers)

Guidance

- If there are minimum outdoor air AND economizer dampers:
    - Make sure the programming keeps the minimum outdoor air dampers completely shut on a schedule for all hours outside of occupancy. This should include morning warm-up/cool-down.
    - For example, if AHUs are scheduled to start-up at 5:00 a.m., but the building is occupied at 7:00 a.m., a separate schedule should keep the outdoor air dampers closed at least until 6:30 a.m.
- If there is a single outdoor air damper:
    - Same principles apply but economizing should take precedence over the schedule (need to still make use of free cooling when appropriate).

Savings

- Climate dependent; see Figure 7.

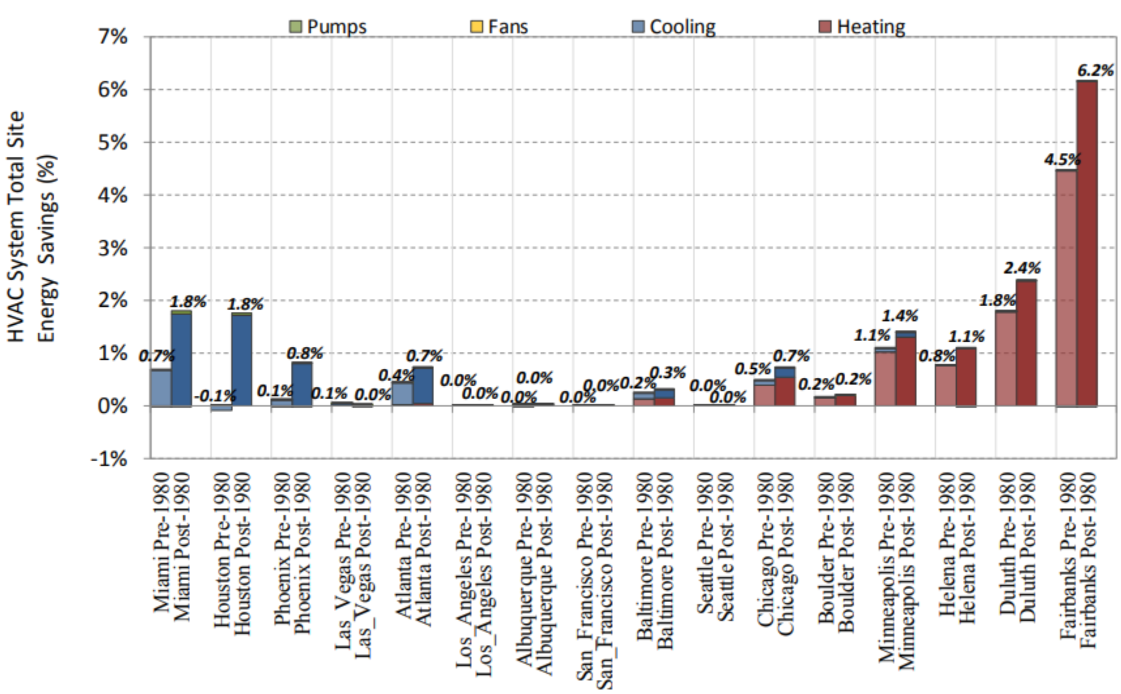

Figure 19: HVAC Savings for A07 Re-tuning Measure (Zero Minimum Outside Air During Unoccupied and Startup Hours)

Figure 7. HVAC savings for zero outdoor air during unoccupied and startup hours (N. Fernandez 2012)

Exhaust Fan Control and Scheduling

Applicability

Building with exhaust fans integrated to the BAS

Guidance

- Ensure bathroom exhaust fans are not interlocked with supply fans, but run on their own, tighter schedule tied to occupancy (starting up to an hour prior to occupancy) and remain off after-hours.
- Scrutinize schedules on other exhaust fans. Ensure that their current schedules reflect their intended function.

Savings

- GSA Portfolio: 1.2% Average Savings Projection, 17% Prevalence of Opportunity

Garage Supply/Exhaust Fan Control

Applicability

Ventilated and heated parking garages

Guidance

- The primary concern with ventilated parking garages is when they are also heated. Continuously ventilating the garage creates an ongoing daily heat load in the winter.
- If there are Carbon Monoxide (CO) sensors in place, ensure that the garage exhaust fans shut off if the CO concentration falls below 30 ppm.
- If there are no CO sensors, consider a scheduled approach that runs the exhaust fans during “rush hours” and cycles the fans on and off for 15-30 minutes at a time in-between.
- Lower the thermostat setpoint for the parking garage if it is too high (>50°F). This will also substantially decrease the required heating.

Savings

- GSA Portfolio: 1.9% Average Savings Projection, 8% Prevalence of Opportunity

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