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Large Commercial Buildings: Re-tuning for Efficiency

Air Handling Units: Pre-Re-Tuning and Trending and Re-Tuning

PNNL-SA-85063 1/11/2012 Version 1.1

Air-Handler Data Analysis

Pre-Re-Tuning Phase:

Air-Handling Units: Trend-data collection and analysis

Re-tuning Phase:

Air-Handling Units: Occupied and Unoccupied Schedule

Air-Handler Data Analysis

- Key conditions to look for while analyzing the charts:
  - Is there any unoccupied operation or 24/7 operation
  - Is there a set back during unoccupied period
  - Lower/higher than expected discharge-air temperature
  - Excessive outdoor-air intake
    - During occupied periods
    - During pre-heating/pre-cooling periods
  - Significant reheat during summer/cooling season
  - Is the supply fan modulating (if VAV)
  - Higher than normal static pressure
  - Set point and static pressure resets
  - Economizer is not utilized or not working properly

Air-Handler Data Analysis

- Enable unoccupied mode and night set back control
- Shut off units at night and weekend
- Turn off heating systems (for reheat only) during summer
  - When reheat system is shut off, room comfort may be maintained by increasing supply-air temperature – for constant volume units
  - Do not turn heating off too early in the summer to avoid having to turn the system on and off repeatedly
- Turn off systems during unoccupied hours
- Slow down systems during unoccupied/lightly and occupied hours

Occupancy Scheduling

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- Shut off systems whenever possible
  - Night unoccupied schedules
  - Weekend unoccupied schedules
  - Daytime no or low use unoccupied schedules
    - Auditorium, class rooms, conference rooms
  - Includes lighting
  - Includes specialized exhaust
  - Do not restart too early
    - Use a startup schedule based on building needs
  - Do not use fresh air during warm-up except last 30 minutes before occupancy, for flushing building

Occupancy Scheduling (continued)

- Shut off systems whenever possible
  - Refrain from starting up system for the occasional nighttime user or weekend user
  - Use bypass buttons
- Unoccupied mode is a major cost saver
  - Simple to implement
  - Simple to track
  - Simple to administer
- Sometimes the least paid employee is the most costly
  - Janitors working at night with all HVAC systems running, fresh at full design conditions and all lights on
  - Is this required?

Occupancy Scheduling (continued)

- During unoccupied and lightly-occupied periods, run fan static pressure at ½ of normal set points, if it does not affect reheat controls
  - Check to make sure heated areas get full air in unoccupied modes
  - Push unoccupied mode air to where it is needed
    - Set VAV boxes in interior zones to unoccupied with 0 air flow
    - Set VAV boxes with reheat (typically on the perimeter) to a high air flow in unoccupied mode, so box will be 100% open during night cycling
      - Air gets to zones needing heat

Occupancy Scheduling (continued)

- Building electric consumption should show significant energy drop for nights/weekends
  - If set backs are active on all HVAC systems
  - Base load versus peak loads should be at least 50% difference and as much as 70% with aggressive set backs
- Trended data for zone temps should show 5-10^{o}F deviations from occupied period set points when set backs are active during non-shoulder months
  - Winter zone temperatures should drop to 60-65^{o}F and summer zone temperatures should rise to 80-85^{o}F

Occupancy Schedule (continued)

- Trended data for discharge static pressures should show readings of 0 in. or at least 50% (half) of normal (occupied) static pressure readings
- If static pressure trend is not available, trended data for main supply/return fan status should indicate “OFF” during unoccupied periods
- Trended data for VAV boxes “occupied/unoccupied” status should indicate “unoccupied” during unoccupied periods
- Trended data for support systems (reheat pumps, reheat converters, reheat hot water boilers, chillers, towers, pumps, etc.) should indicate they are turning off at night, if all areas of the building are also shut down

Occupancy Schedule (continued)

- Unoccupied periods should include weekends, holidays and night hours during work week periods
  - If facility has sporadic use periods, this may require additional efforts to succeed at implementing set backs
- Make sure the “tail” is not “wagging the dog” – janitors, special events, extreme weather events, overrides, etc.
- How does your organization respond to trouble calls (occupant complaints)? How do you respond? Is the response a “band-aid” or a long-term solution? Overrides on schedules are not long-term solutions

Occupancy Schedule (continued)

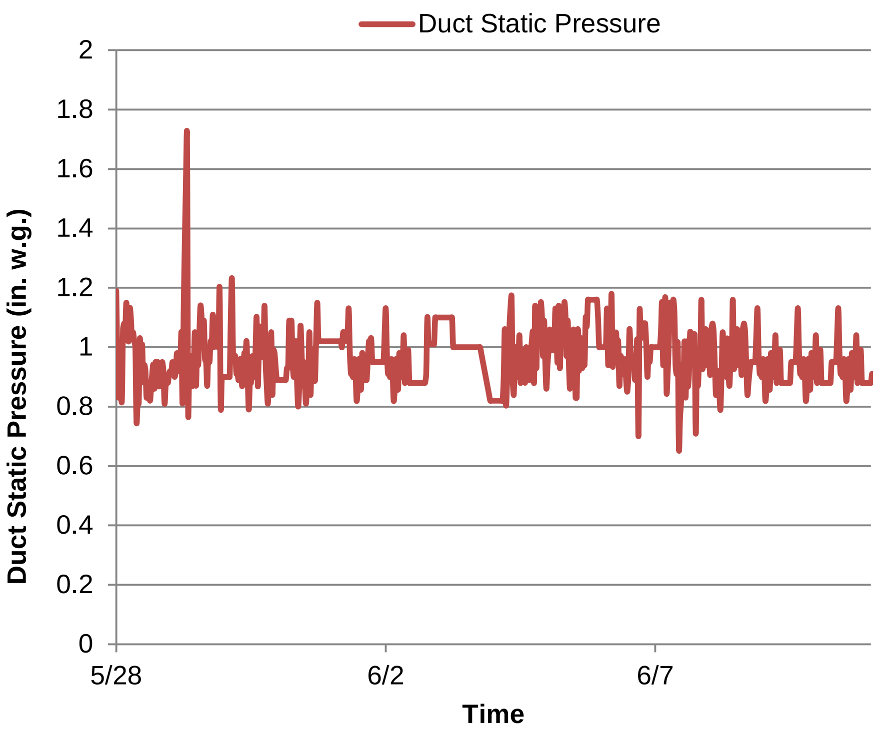
- Empower occupants to control their ventilation when they need it
  - Most building designs provide occupants with local light switches for local lighting control
  - Does your DDC system provide similar capabilities for ventilation so occupants can obtain ventilation automatically when they need it (motion sensors, timed overrides, Outlook scheduling of conference rooms or other “special” spaces)?
- Consider adding outdoor-air temperature interlocks that “override” the occupied schedule, anytime the outdoor-air temperature exceeds the design parameters
  - This will eliminate overrides that are left in place and should only be active 2-4 weeks/year
- Does your DDC system have “scheduling” capability?
  - Do you know how it works?
- Does your DDC system have “optimal start/stop” scheduling capability?
  - Are you using it?

Night and Weekend Temperature Set back and Supply-Fan Cycling

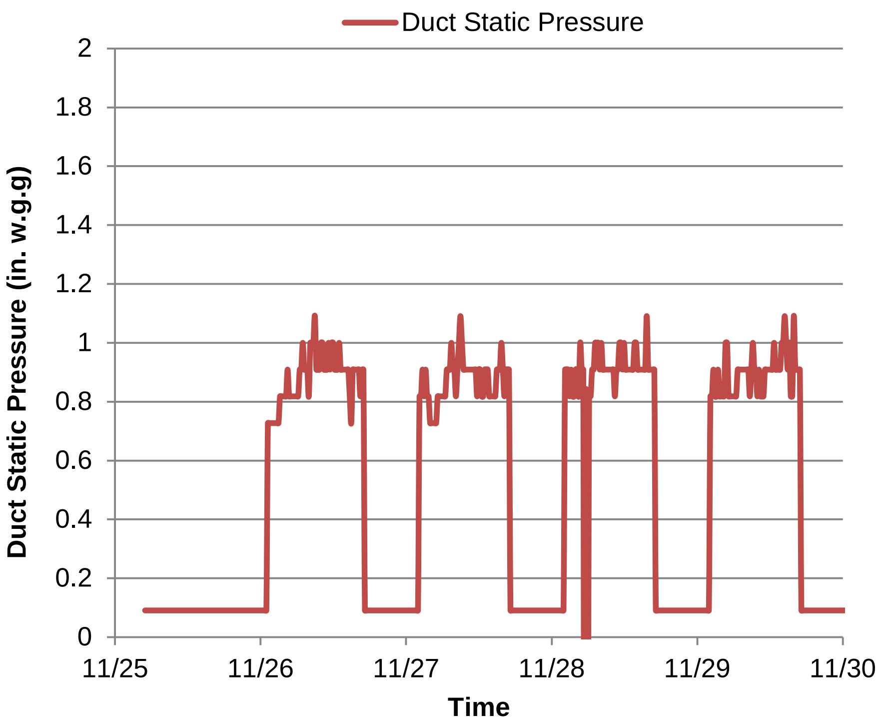
- Purpose:
  - Determine whether night and weekend temperature set back is being used effectively
  - Check for unusually frequent supply-fan cycling
- Approach:
  - For each monitored air-handler, plot supply fan status vs. time
  - Look for off status during scheduled off times, for the served zones to be unoccupied (nights and weekends)
- Potential issues to identify
  - No night set back for heating or cooling
  - No weekend set back for heating and cooling
  - Excessive supply fan cycling

Night and Weekend Temperature Set back and Supply-Fan Cycling (continued): Example use of Graphs

Duct static pressure can be used to identify the system operation



Bad Operation



Good Operation

Night and Weekend Temperature Set back and Supply-Fan Cycling (continued): Bad Example

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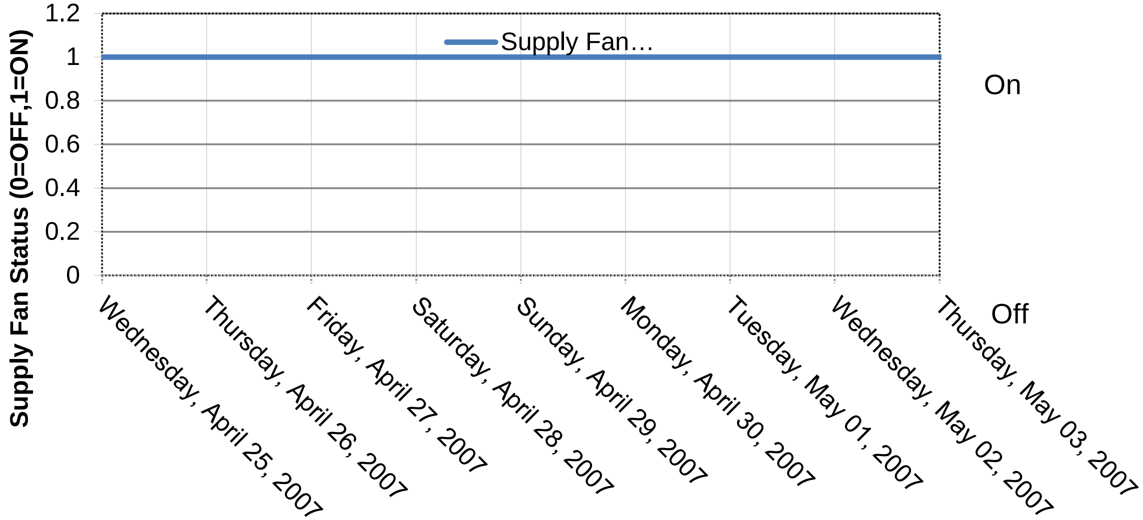
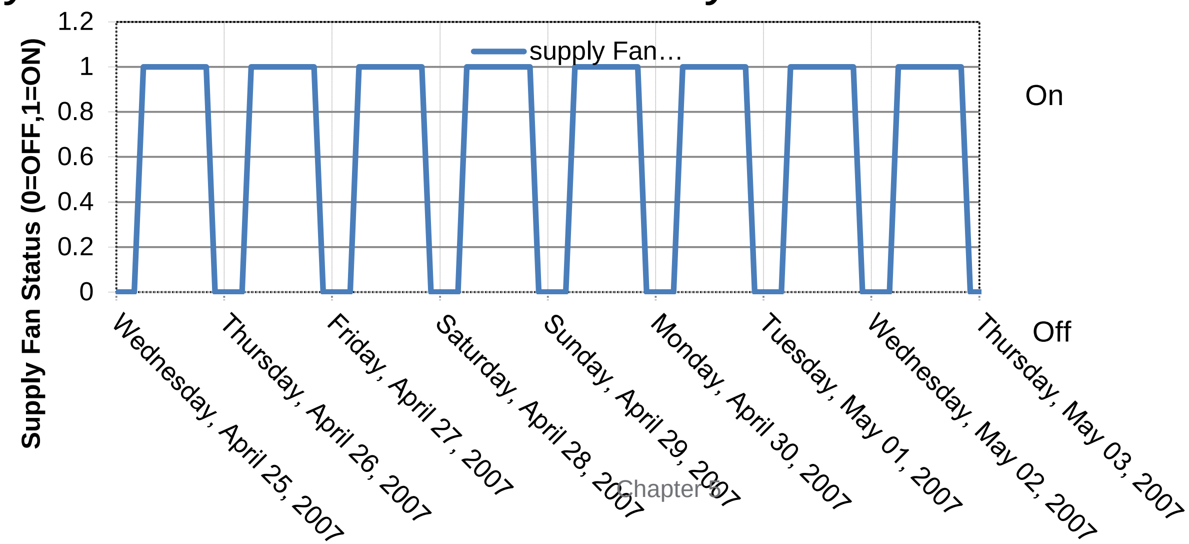
- Supply fan status vs. time – AHU runs 24/7(Example of bad operation)

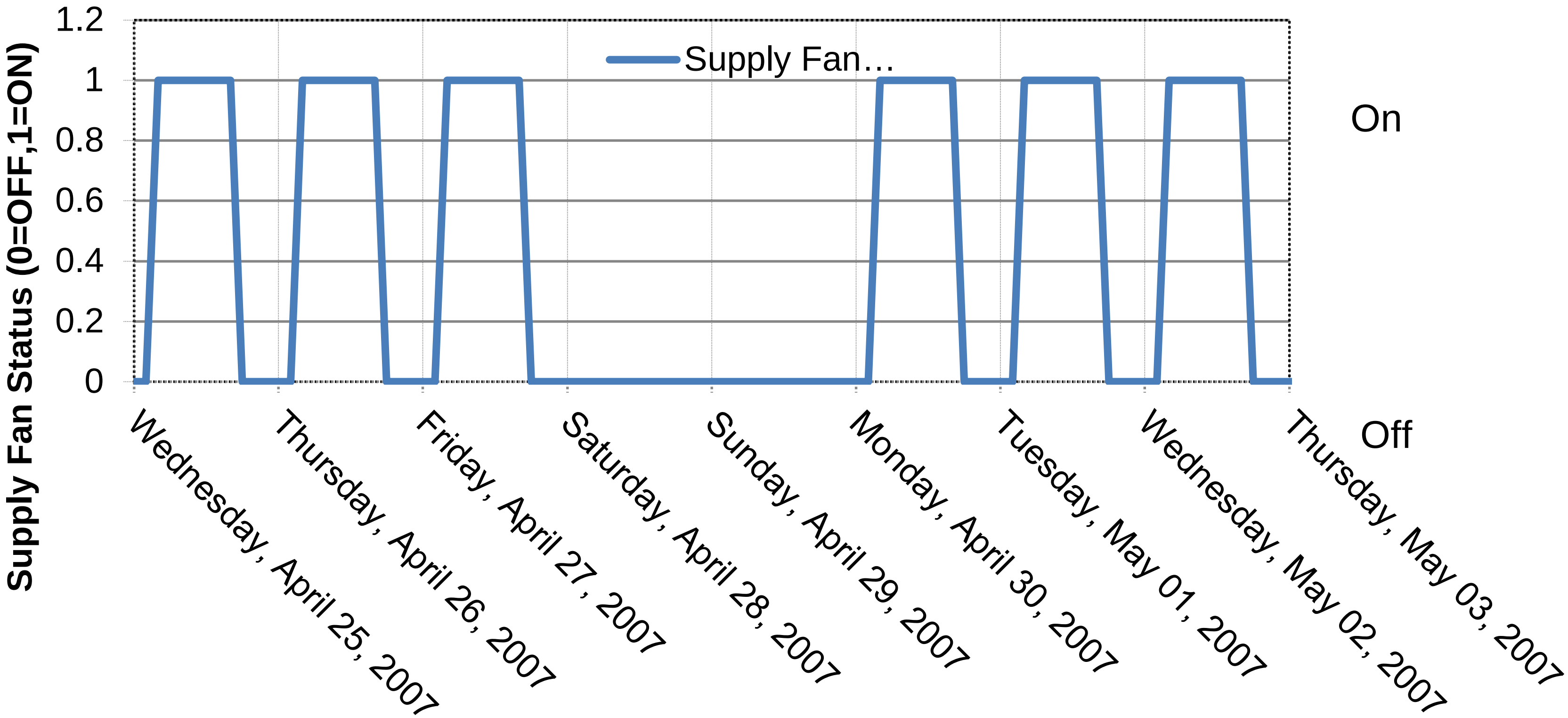


- Supply fan status vs. time – Possibly OK but no weekend set back

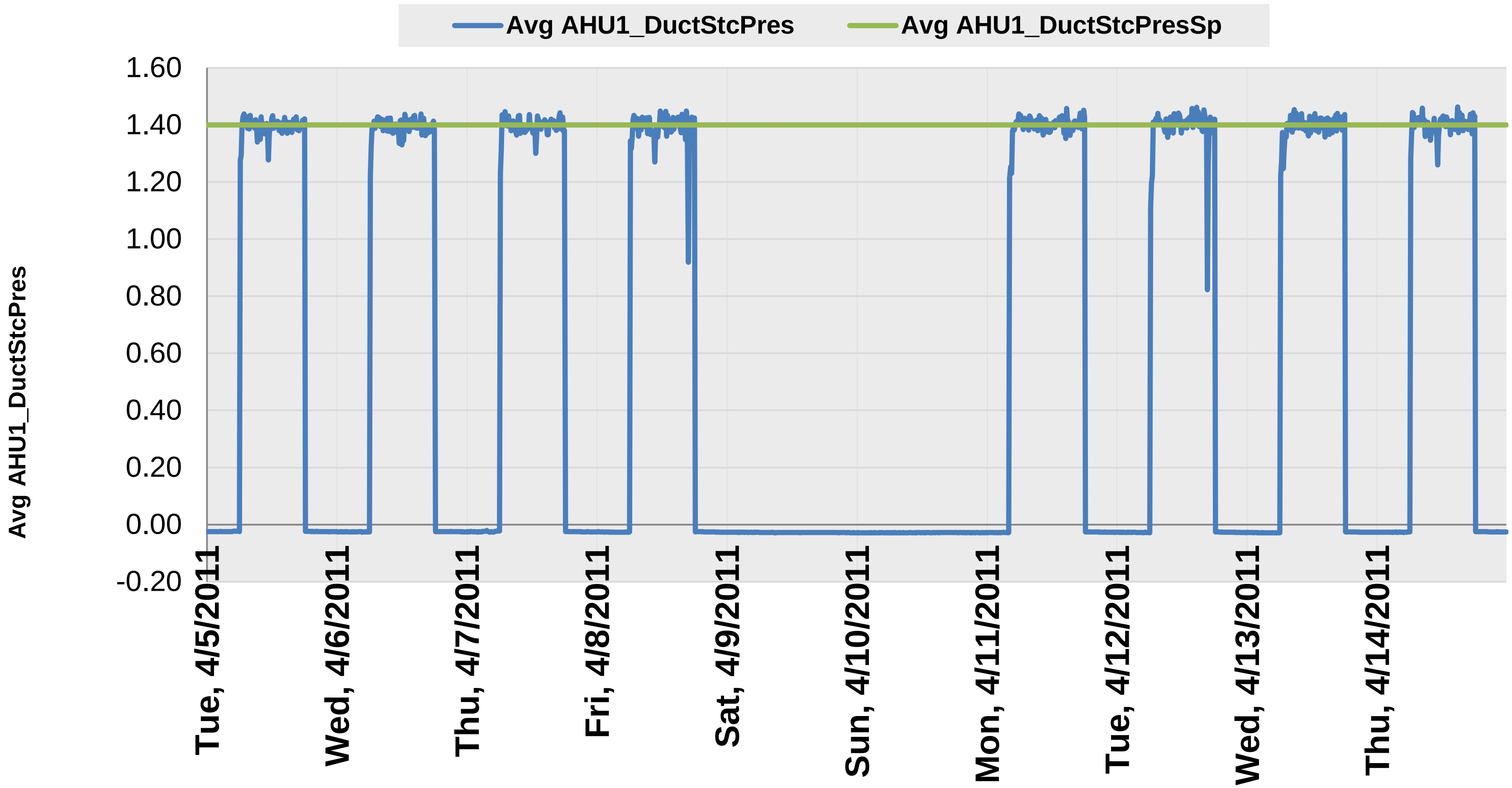


Night and Weekend Temperature Set back and Supply-Fan Cycling (continued): Example use of Graphs

- Supply fan status vs. time – Better – Longer night set back and weekend set back

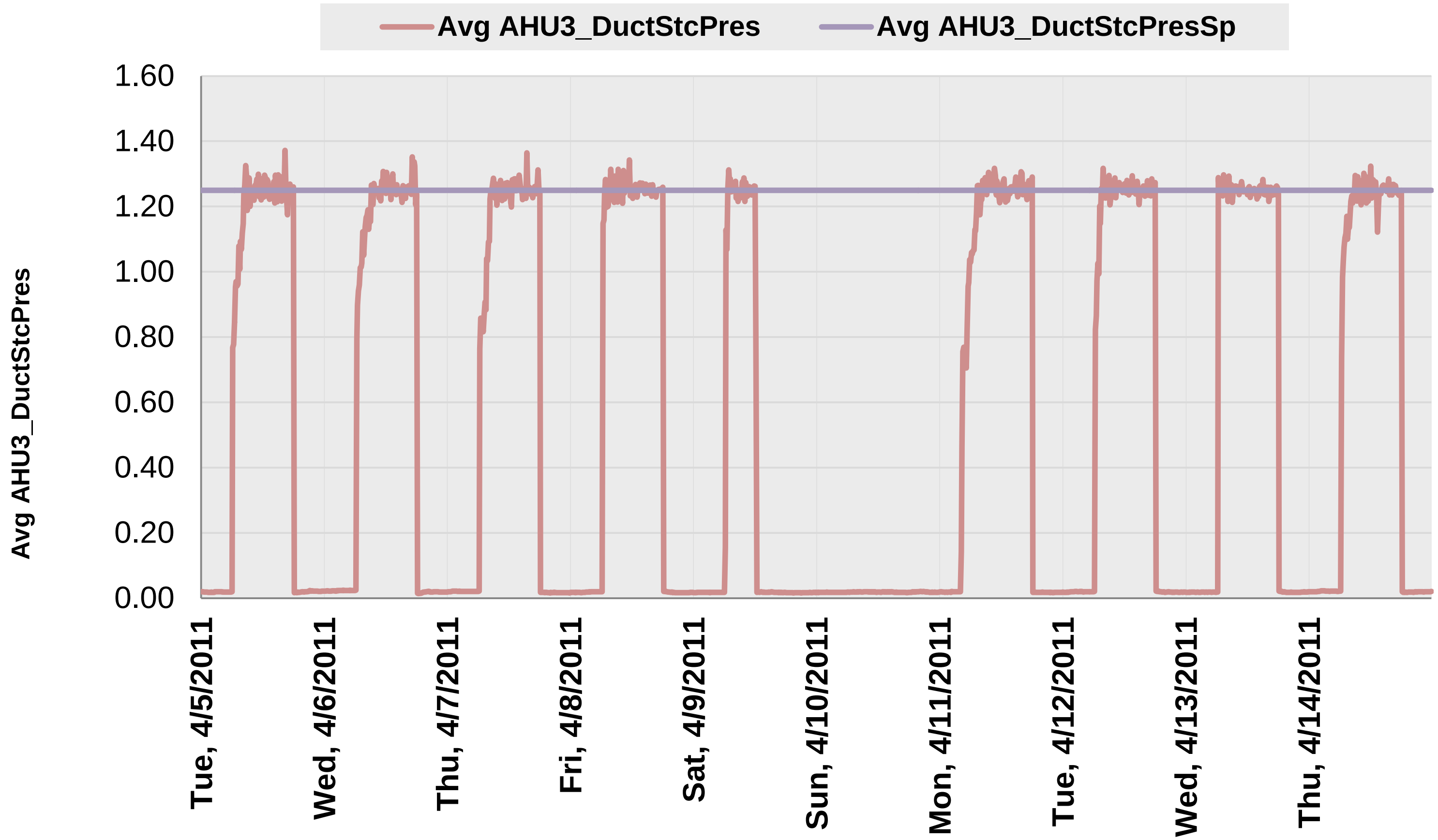


Checking Schedule with Supply Fan Static Pressure



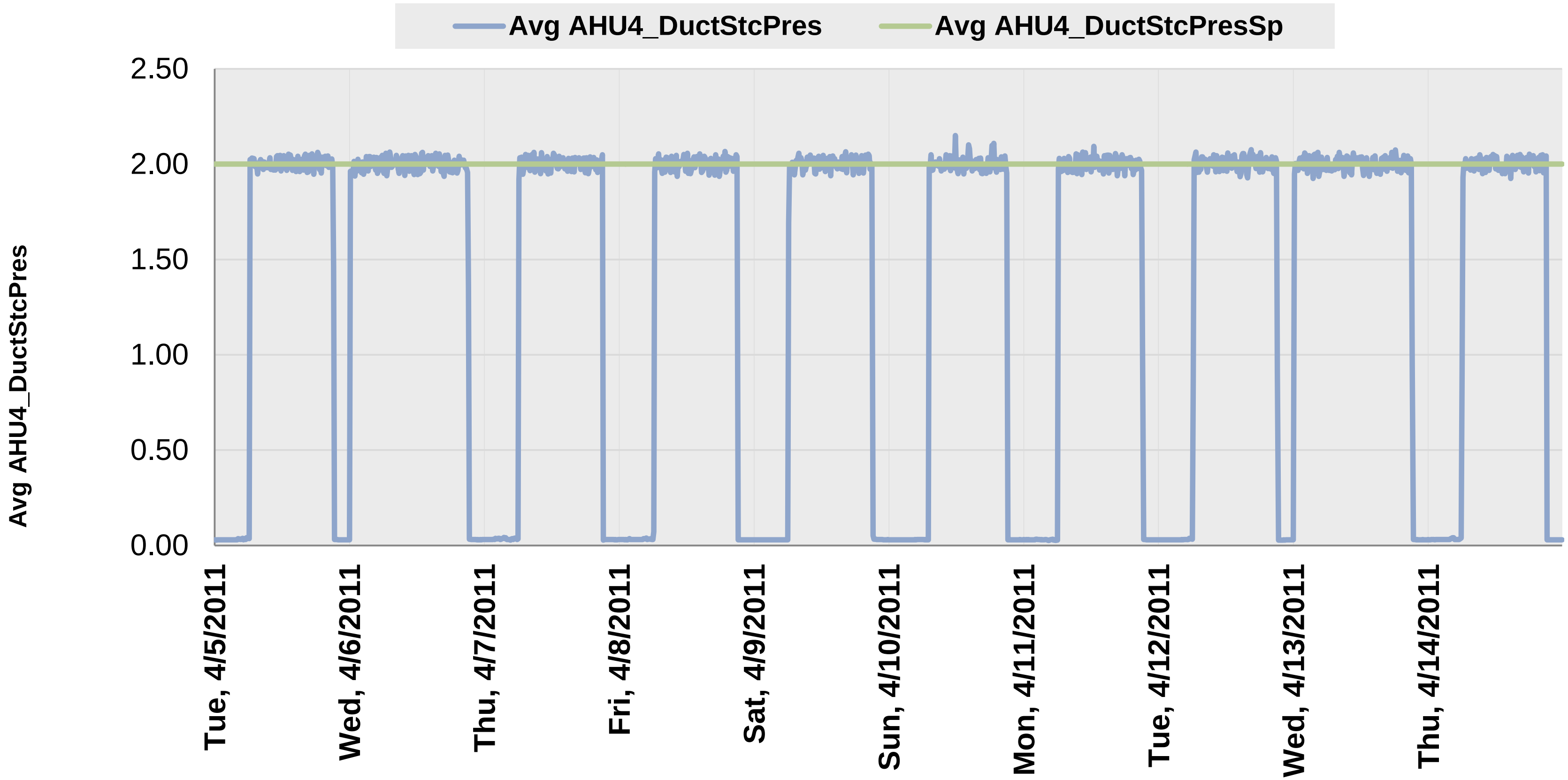
Example of Good Operation

Checking Schedule with Supply Fan Static Pressure



Example of Good Operation

Checking Schedule with Supply Fan Static Pressure



Opportunities?

Air-Handler Data Analysis

- Pre-Re-Tuning Phase:
  - Air-Handling Units: Trend-data collection and analysis of discharge-air temperature

- Re-tuning Phase:
  - Air-Handling Units: Discharge-air temperature set point

Air-Handler Data Analysis: Discharge-Air Temperature Set Point

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- Purpose
  - Review discharge-air temperatures for the air-handlers
  - Determine whether discharge-air temperatures are maintained relatively stable
  - Determine whether the discharge-air temperatures are too cool or too warm
- Approach
  - For each air handler monitored, review plots of discharge-air temperature and discharge-air temperature set point vs. time and discharge-air temperature vs. discharge-air temperature set point
  - Look for deviations between discharge-air temperatures and set points
  - Look for unusually high (>70°F) or low (<55°F) discharge-air temperatures

Air-Handler Data Analysis: Discharge-Air Temperature Set Point

- Potential issues to identify
  - Discharge-air temperature not meeting discharge-air temperature set point
  - Unusually unsteady discharge-air temperatures
  - Reset not being used for discharge-air temperature set point
  - Discharge-air temperature set point too high or too low

Discharge-Air Temperature Control

- One of the most important variables in a HVAC system:
  - Low discharge-air temperature will cause:
    - Overcooling
    - Reheating in cooler zones
    - Portable heaters in offices
    - Drafts and cold complaints
    - Extra load on the cooling plant
    - Excess discharge-air pressure
    - Excess energy in reheating the overcooled zones

Discharge-Air Temperature Control (continued)

- Discharge-air temperature needs to be set low enough to handle the peak cooling load
  - Summer weather peak
  - Interior load peak
  - Staffing peak
  - Maybe 1% to 2% of the operating hours are at this condition, yet most systems run 100% of the time at this set point
- Reheat makes up for all areas that are too cold from a lower than needed discharge-air temperature

Discharge-Air Temperature Control (continued)

- Discharge-air temperature can run as high as possible and still meet the cooling needs
  - VAV boxes can run at higher air flows
  - Return-air can be warmer and help heat building
  - Reheats will run a lot less
  - Staff complaints go down due to less cold drafts
  - Building is ventilated better
- Reheat has to make up for all areas that are too cold from a lower than needed discharge-air temperature

Discharge-Air Temperature Control (continued)

- What is driving the current discharge-air temperature set point? Why is it set where it is?
  - Engineered setting per drawings before building was built
  - Field engineer
  - Building/facility manager
  - Technician best guess
  - Current weather conditions
  - Loudest customer complaint
  - Because that is where its always been, so it must be right
  - ???????? ENERGY COST ???????

Discharge-Air Temperature Control (continued)

- Does the discharge-air set point vary with some input signals? > 55°F – < 70°F
- Set up a discharge-air temperature set point reset schedule based on the personality of the zones it feeds
- Examples:
  - Warmest 3 zones averaged
    - For example reset, if average zone temperature is 76°F, then discharge-air temperature should be 55°F
    - If average zone temperature is 72°F, discharge-air temperature can be as high as 65°F
  - Number of reheats running
    - 10 out of 15 zones in heat, then the discharge-air temperature can be as high as 70°F
    - 2 out of 15 zones in heat, then discharge-air can be as low as 55°F
  - Coolest perimeter zone
  - Outdoor-air temperature
    - If outdoor-air temperature is 50°F, then the discharge-air is 70°F
    - If outdoor-air temperature is 75°F, then the discharge-air is 55°F

Discharge-Air Temperature Control (continued)

- Occupant complaints (if many) could be a precursor to an improperly working (or non-functioning) discharge-air temperature control scheme
- Trended data for discharge-air temperatures that is “flat” or rarely varies is a strong indicator of a non-functioning discharge-air temperature “reset” control
- Trended data for discharge-air temperatures that show sharply falling temperatures well below set point that are coincidental to the chiller system starting and remain well below set point are indicative of a failed (leaking) cooling control valve
- Trended data for discharge-air temperatures that show sharply rising temperatures well above set point that are coincidental to the boiler/reheat system starting and remain well above set point are indicative of a failed (leaking) heating control valve

Discharge-Air Temperature Control

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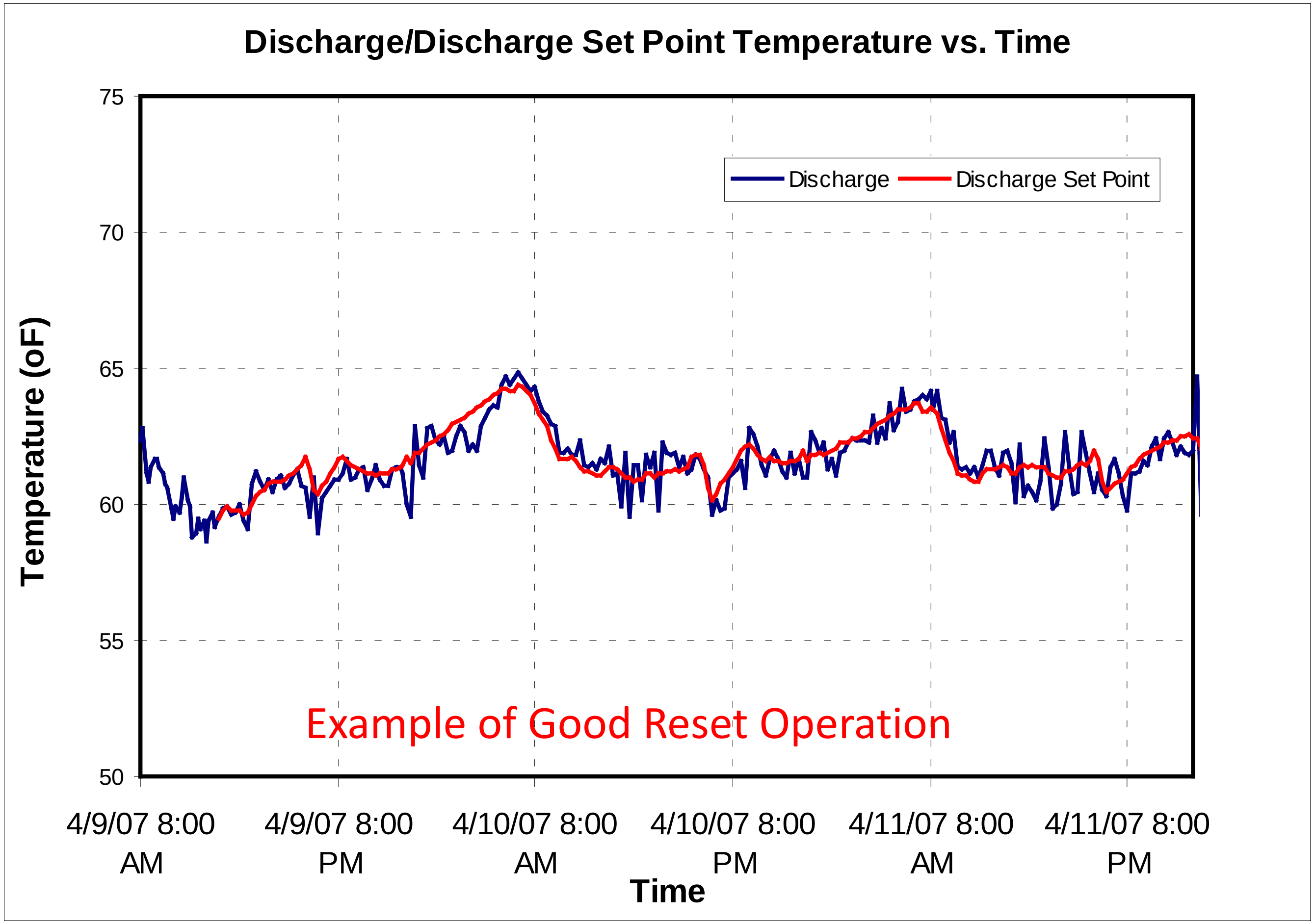
- Trended data for discharge-air temperature "reset" control that is working should show temperature set points that vary as the building "wakes up" in the morning hours and then changes as the building becomes occupied and continues to change during the late morning and early afternoon hours and continues to see changes due to changing outdoor ambient temperatures and solar loading. This can vary as much as 10 to 15^{o}F over the course of the day
- Does your DDC system already calculate: warmest zone temperature, lowest zone temperature, average zone temperature?
  - If not, then it is doubtful that your DDC is set up to reset the discharge-air temperature set point based upon a feedback that reflects true building load conditions
- Does your DDC system currently reset the discharge-air temperature set point using either outside-air temperature or return-air temperature?
- Preferred order to reset discharge-air temperature is from zone conditions, return-air temperature and then outside-air temperature

Discharge-Air Temperature Control

- Summer mode (for example, outdoor-air temperature >75ºF):
  - Set discharge-air temperature set point at 55ºF
  - Shut off heating coil valve
- Winter mode (for example, outdoor-air temperature <60ºF):
  - Set discharge-air temperature set point at 65ºF, if less than 40% of zones require cooling
  - If more zones call for cooling than heating, discharge-air temperature set point can be lowered to 55ºF
  - Shut off the cooling coil valve, if the freeze protection is not enabled
- Heating and cooling valves can be closed when outdoor-air temperature is in between summer mode and winter mode

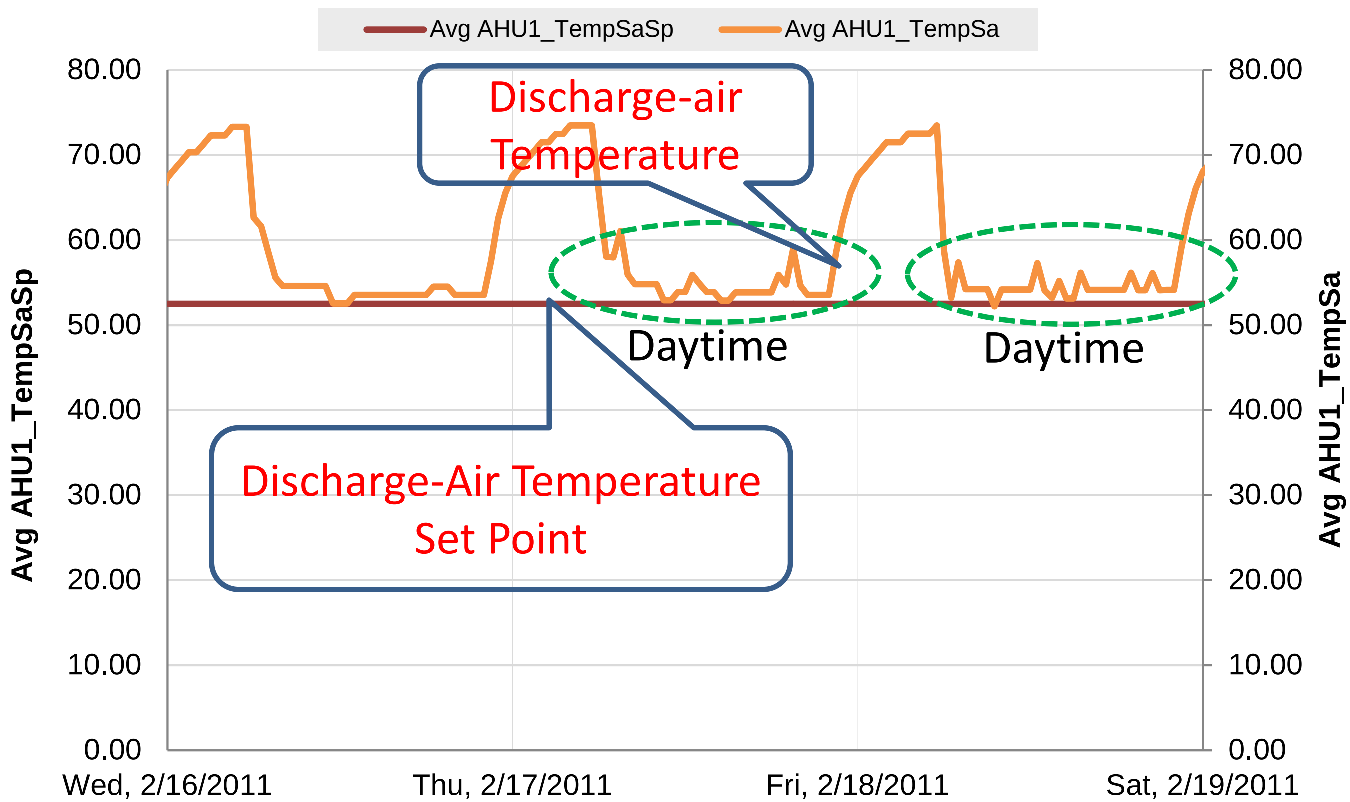
Air-Handler Discharge-Air Temperatures: Example use of Graphs

- Discharge-air temperature and discharge-air temperature set point vs. time – 3 days



Air-handler Discharge-Air Temperatures: Example use of Graphs

- Discharge-air temperature and discharge-air temperature set point vs. time – 3 days



Example of Bad Operation - No Reset (Constant day and night)

Air-handler Discharge-Air Temperatures: Example use of Graphs

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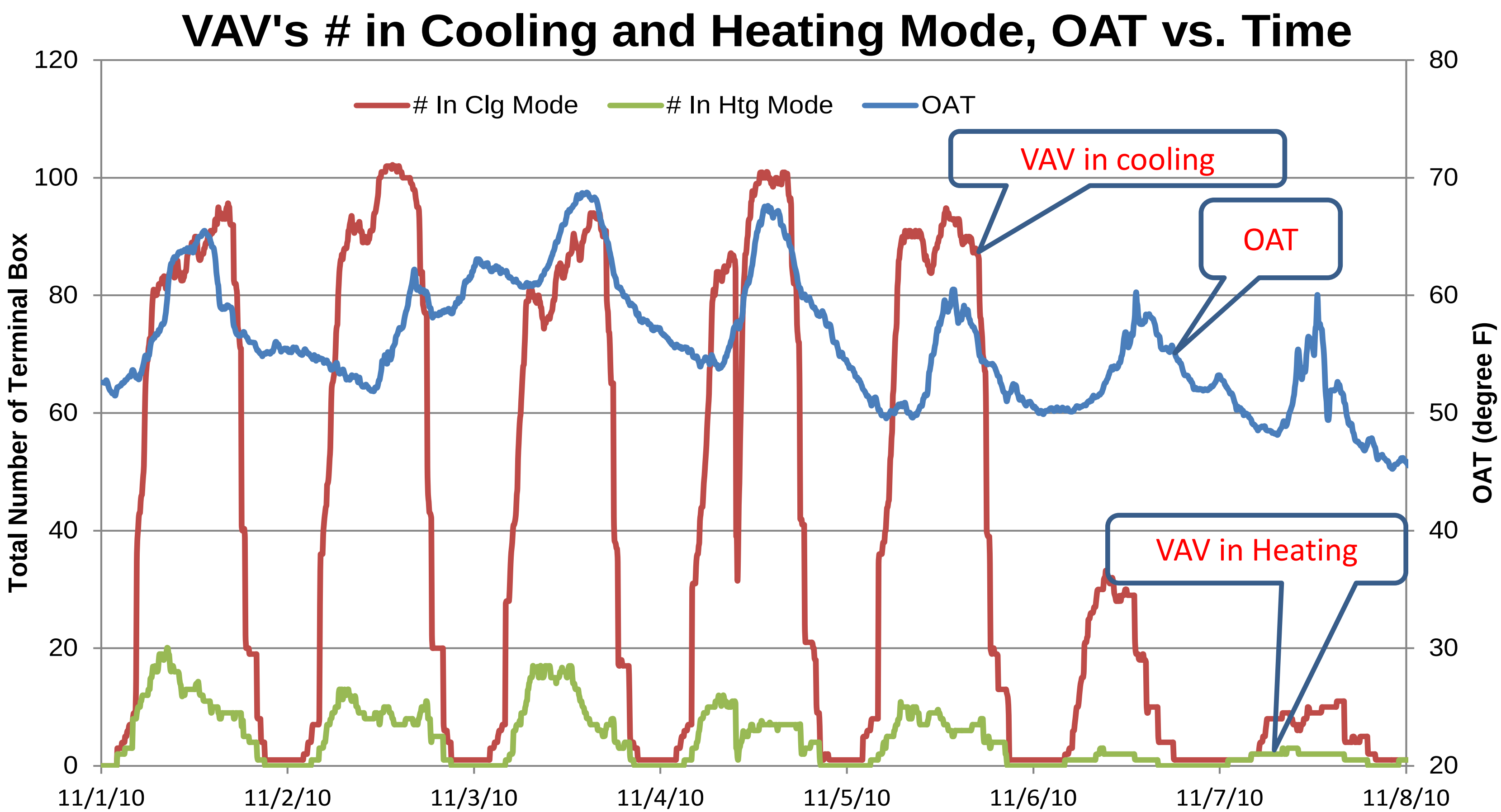
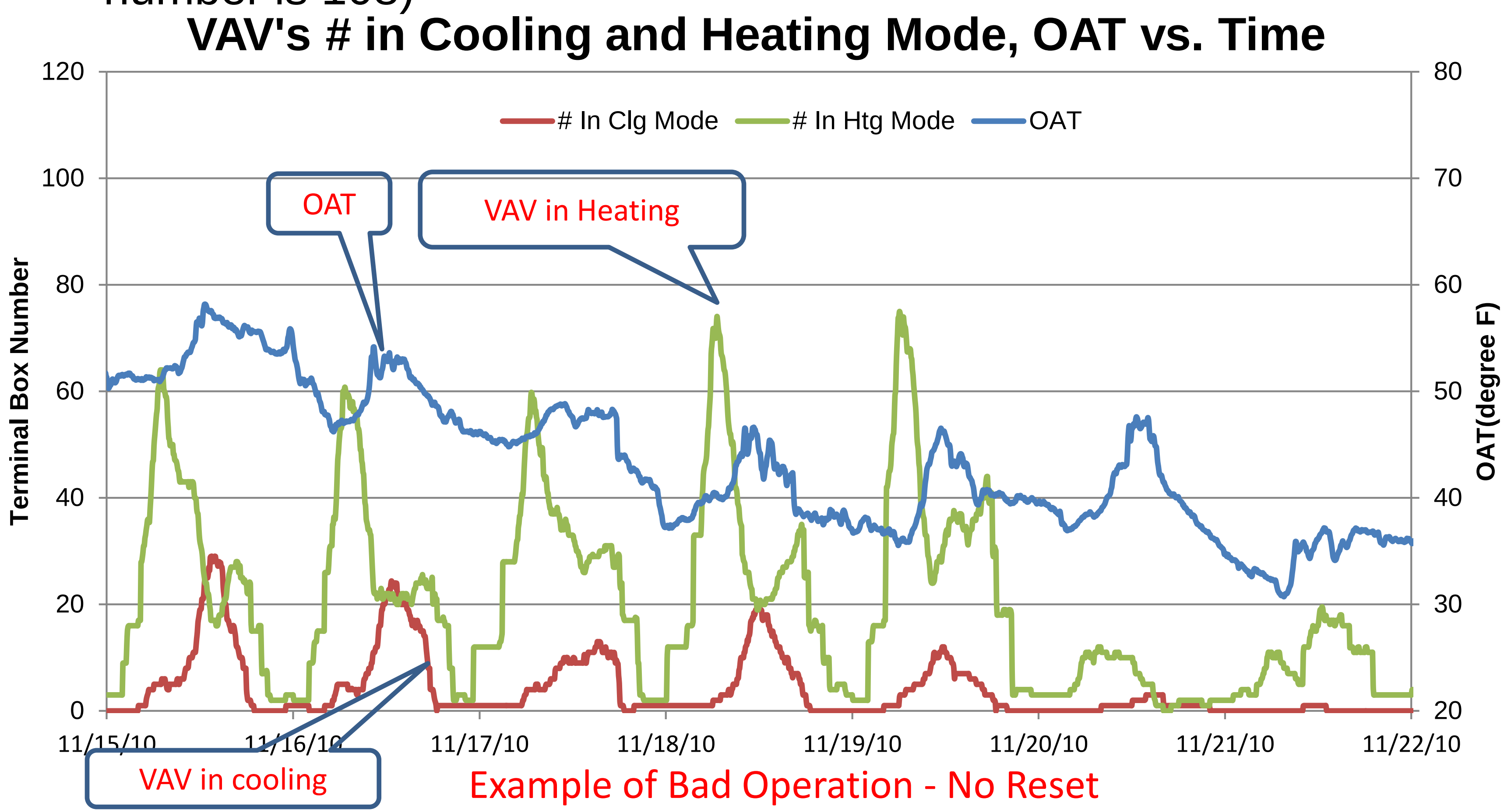
- Opportunity to decrease the discharge-air temperature (total VAV terminal box number is 279)



Example of Bad Operation - No Reset

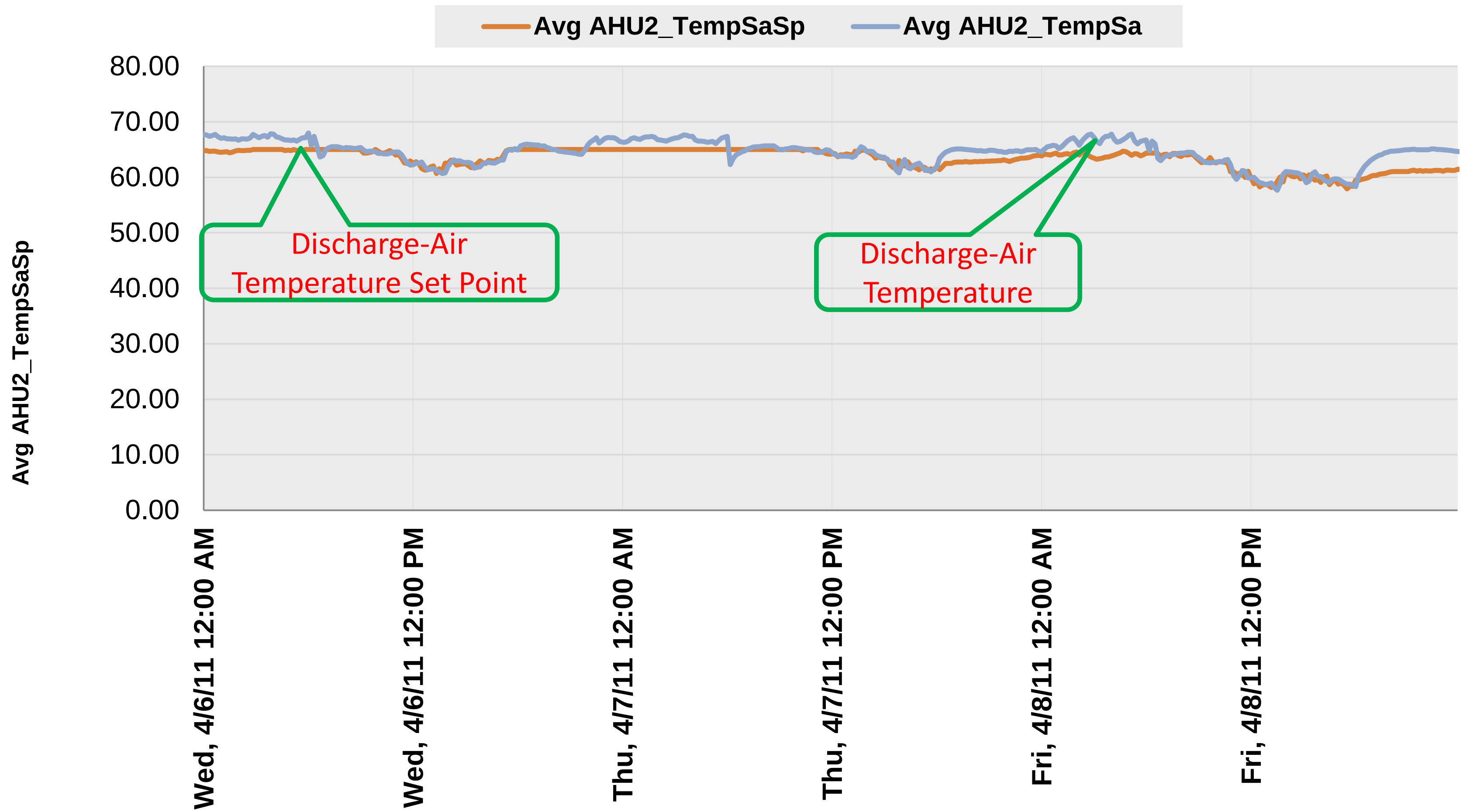
Air-Handler Discharge-Air Temperatures: Example use of Graphs

- Opportunity to increase the discharge-air temperature when outdoor-air temperature (OAT) is lower than 50ºF (total VAV terminal box number is 108)

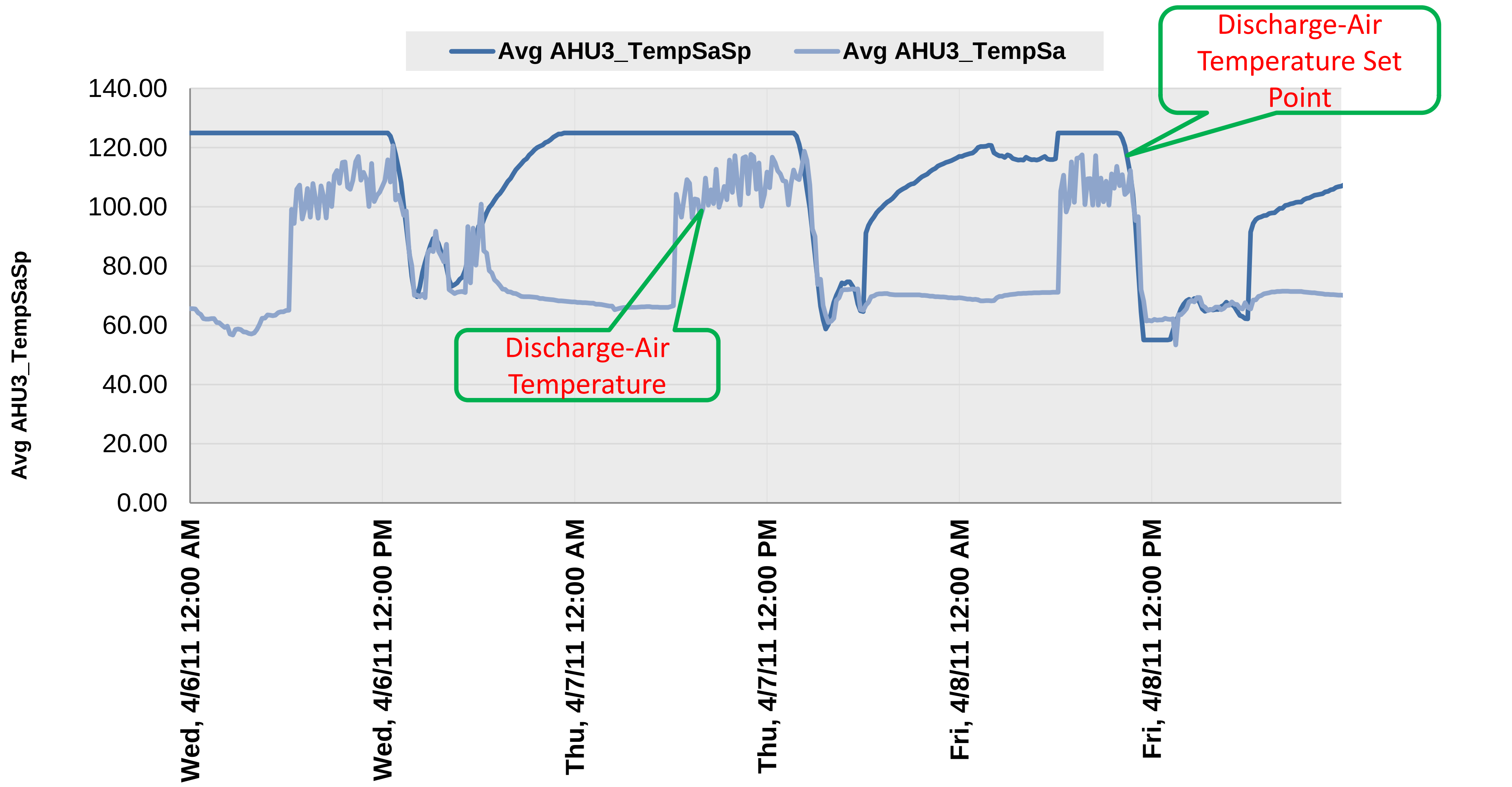


Example of Bad Operation - No Reset

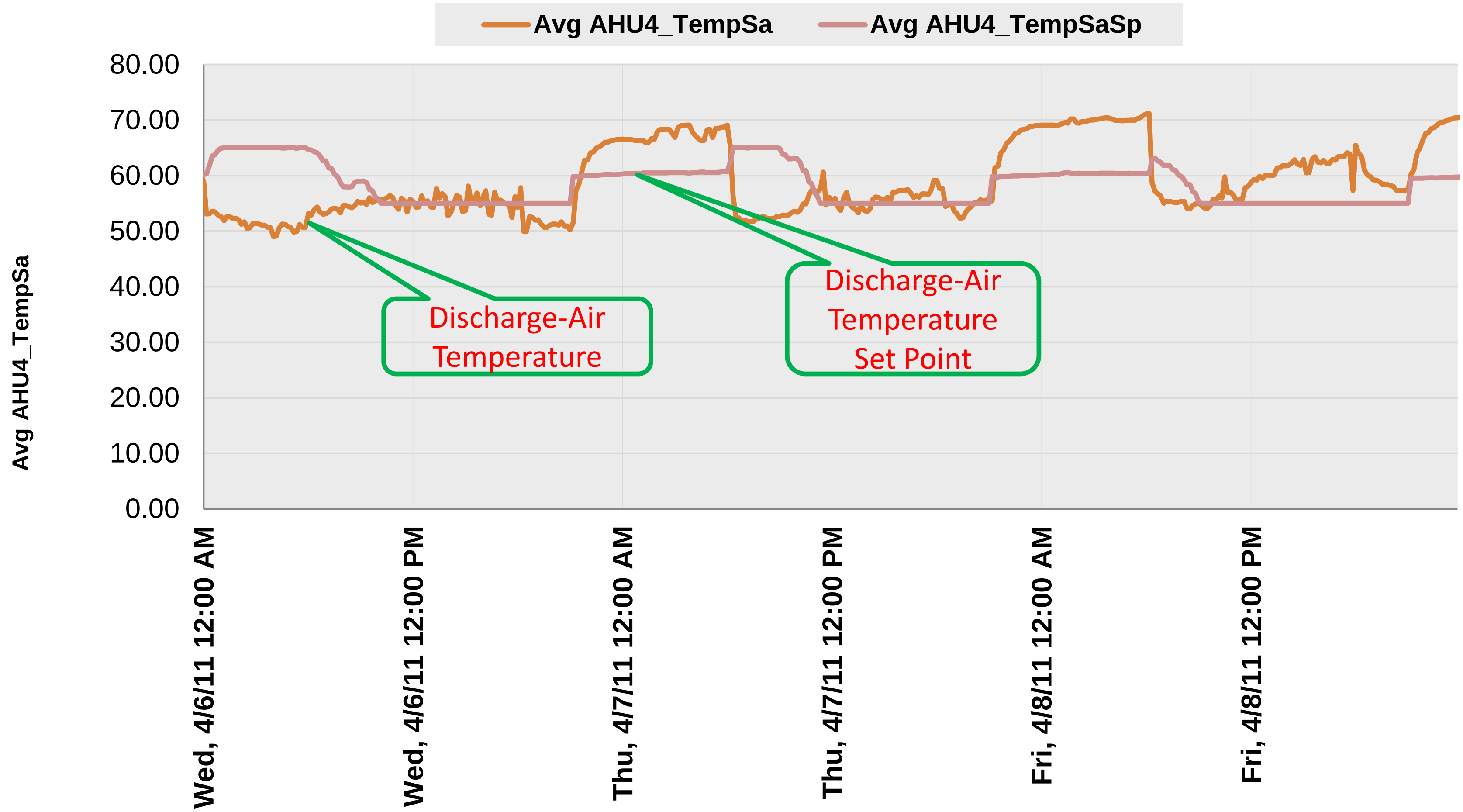
Discharge-Air Temperature Control



Discharge-Air Temperature Control



Discharge-Air Temperature Control



Air-Handler Data Analysis: Static Pressure

- Pre-Re-Tuning Phase:
  - Air-Handling Units: Trend-data collection and analysis for duct static pressure

- Re-tuning Phase:
  - Air-Handling Units: Duct static pressure

Air-Handler Data Analysis: Static Pressure

- Purpose: Determine whether the static pressure set point is too high or too low or if static pressure is changing over time
- Approach:
  - For each air handler, review a plot of the damper positions of all VAV units vs. time
  - Look for situations where:
    - Most dampers are nearly closed during cooling – static pressure too high
    - Several VAV boxes on an air handler have dampers fully open – static pressure is too low and VAV boxes are not able to meet zone loads – starved boxes
    - Dampers are not modulating as conditions change – VAV boxes that are not being controlled or not responding to control signals

Static Pressure Control

- Does the static pressure vary with some input signals?
  - Like discharge-air temperature, static pressure should follow the real load conditions
    - Too high and VAV boxes have trouble controlling
    - High noise levels in ceiling or at diffusers coming from VAV box
    - Extra load on air handler not required
      - Higher CFMs
      - More chiller load
      - More fan wear and belt wear
      - Higher fan energy cost. **horsepower** varies with the **CUBE** of the **speed**
  - Ideally, VAV dampers should run in the 50% to 75% range (non-design conditions)

Static Pressure Control

- **Static pressure control specifications taken directly from a vendor's standard specifications**
- **VAV control**
  - **STATIC PRESSURE CONTROL:** THE SUPPLY FAN WILL MODULATE TO MAINTAIN THE DISCHARGE STATIC PRESSURE SET POINT
    - Who determines set point? Normally a computer before the building is ever built!
- Control contractors are not actively coding in intelligent control functions unless an engineer asks for it
- Engineers are designing to basic design conditions and are not concerned about system control in shoulder conditions

Static Pressure Control (continued)

- Use a reset schedule based on damper position
  - Read all damper positions
  - Sort by descending position, highest to lowest
  - Reset discharge static to maintain the average of the 3rd highest to the 7th highest positions to about 75% open
    - Do not use failed dampers or outliers in calculations
- Main idea is match control point to actual need
- Example would be systems that run at 0.5 in. in the morning and 2 in. in the afternoon when fully loaded

Static Pressure Control (continued)

- Example of cause and effect
- Discharge pressure transmitter failed
  - Fan failed at full speed
- Building owner determined not to fix it because tenants did not complaint
- Utility bill went up several thousands of dollars over a 1-year period
  - Utility bill is passed on to tenant
- Tenant finally complained about increase and then helped owner determine cause
- Owner did the $100 repair
- The utility bill dropped thousands of dollars!

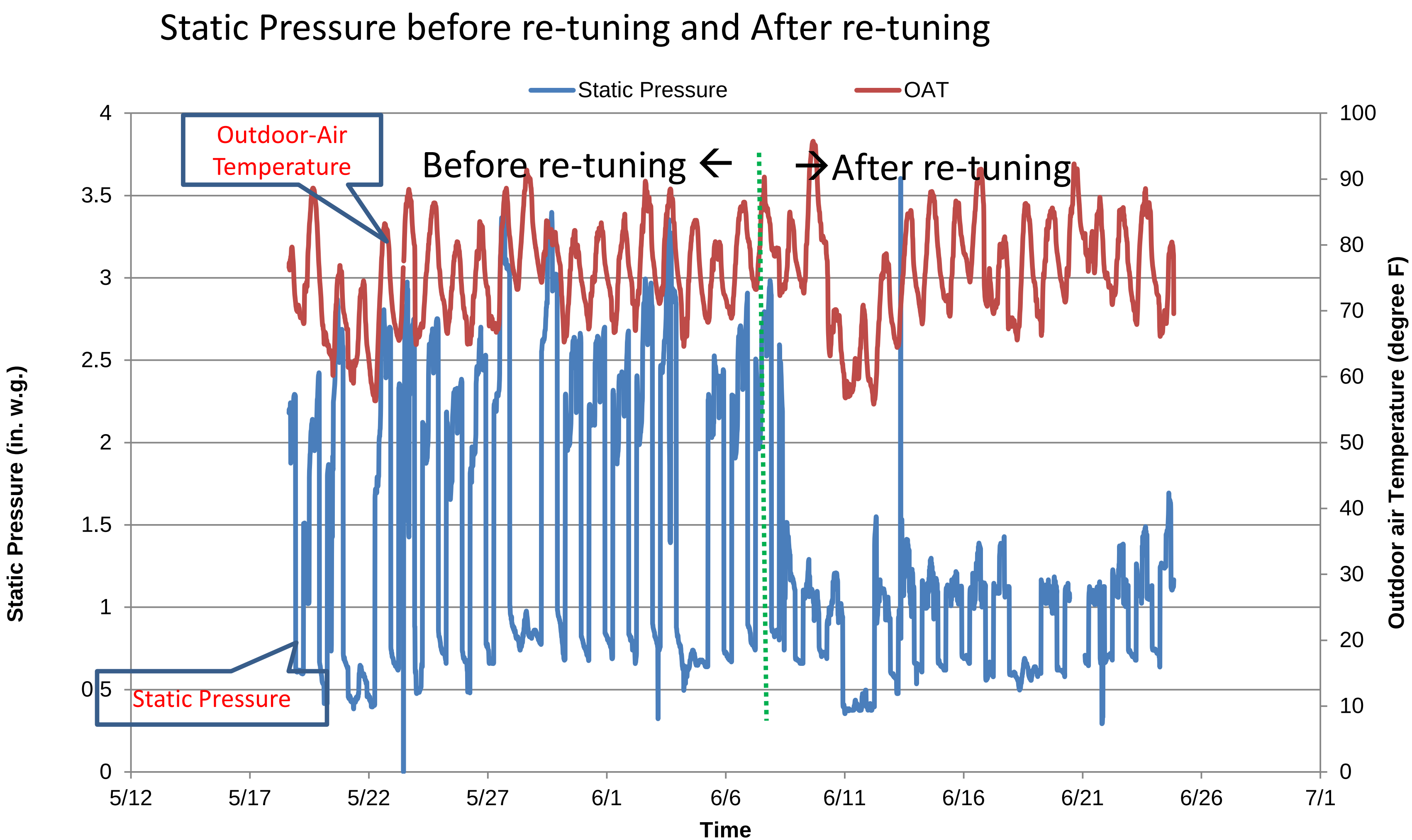
Static Pressure Control (continued)

- Occupant complaints (if many) could be a precursor to an improperly working discharge static pressure control scheme
- Excess static pressure can result in excess air and cold drafts as well as high noise levels in office spaces from diffuser noise
- Excess supply fan static pressure can result in outside-air being “drawn” into the mixing box plenum section, via the exhaust damper
- If this is observed in field walk-downs, verify that the return fan is operating correctly; otherwise, excess supply static pressure should be one suspect

Static Pressure Control (continued)

- Trended data for static pressure control that is working should show static pressure varying
  - Set points that vary as the building “wakes up” in the morning hours and then changes as the building becomes occupied and continues to change during the late morning and early afternoon hours and continues to see changes due to changing outdoor ambient temperatures, solar loading and internal gains
- If the static pressure control is constant, then the fan speed (load) should vary as noted above

Static Pressure Reset Based on Terminal Box: Example of Good Operation



Example for Bad and Good Operation

Static Pressure Reset Based on Terminal Box: Example of Good Operation

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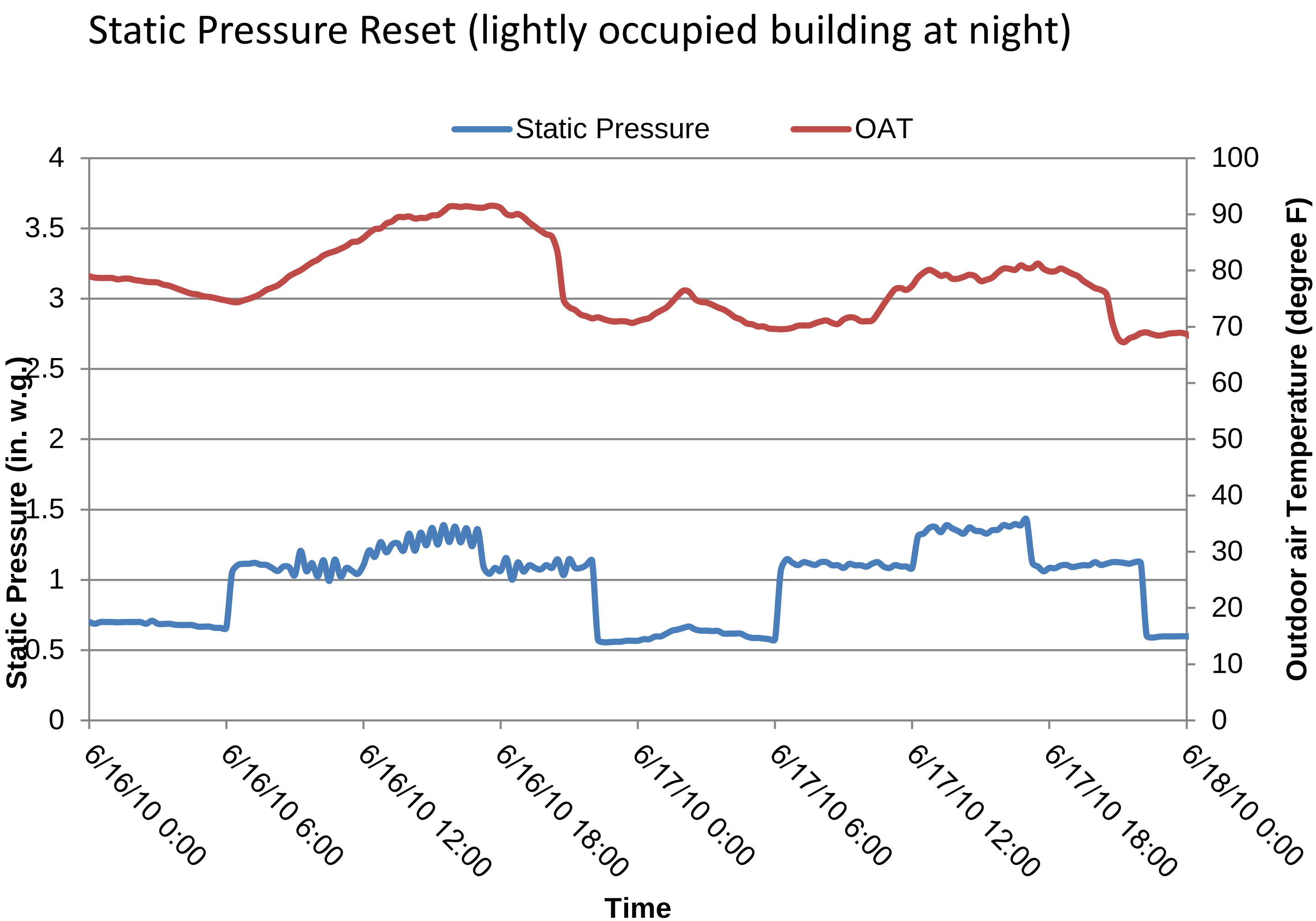

Example of Good Operation

No Static Pressure Reset: Example of Bad Operation - Constant Day and Night

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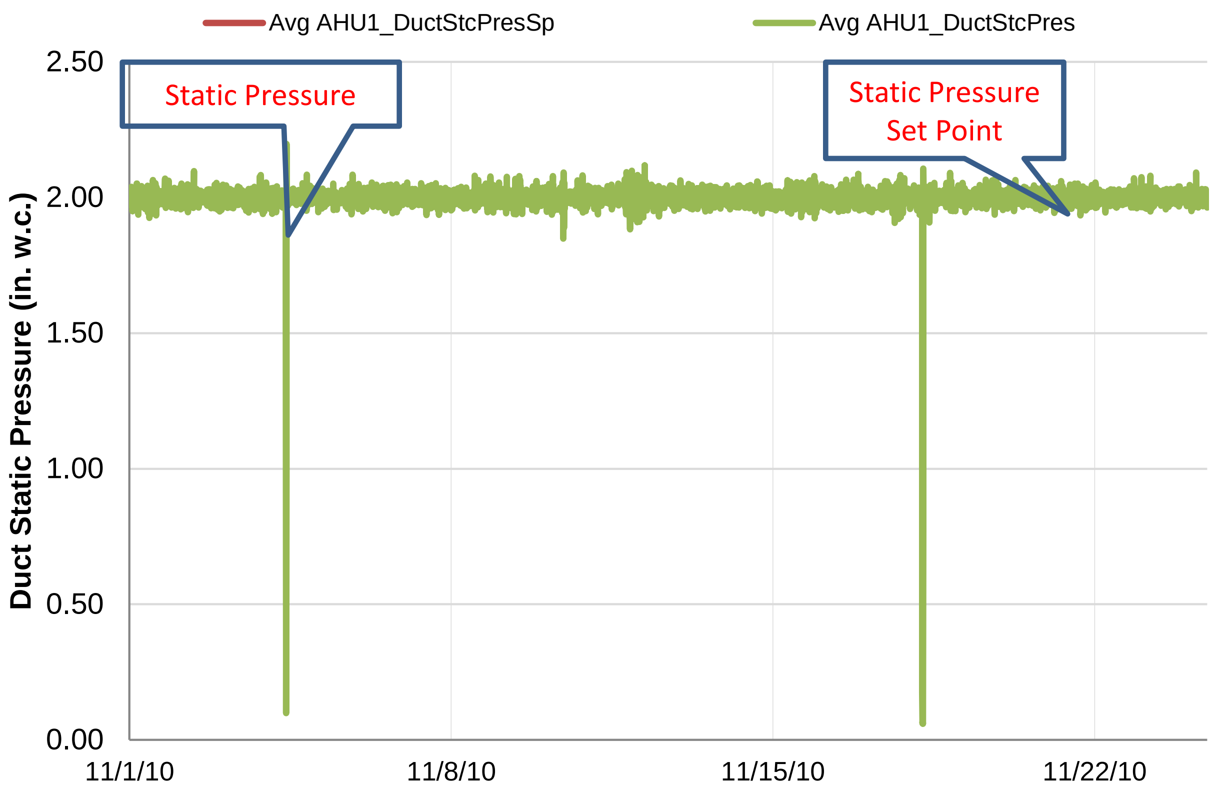
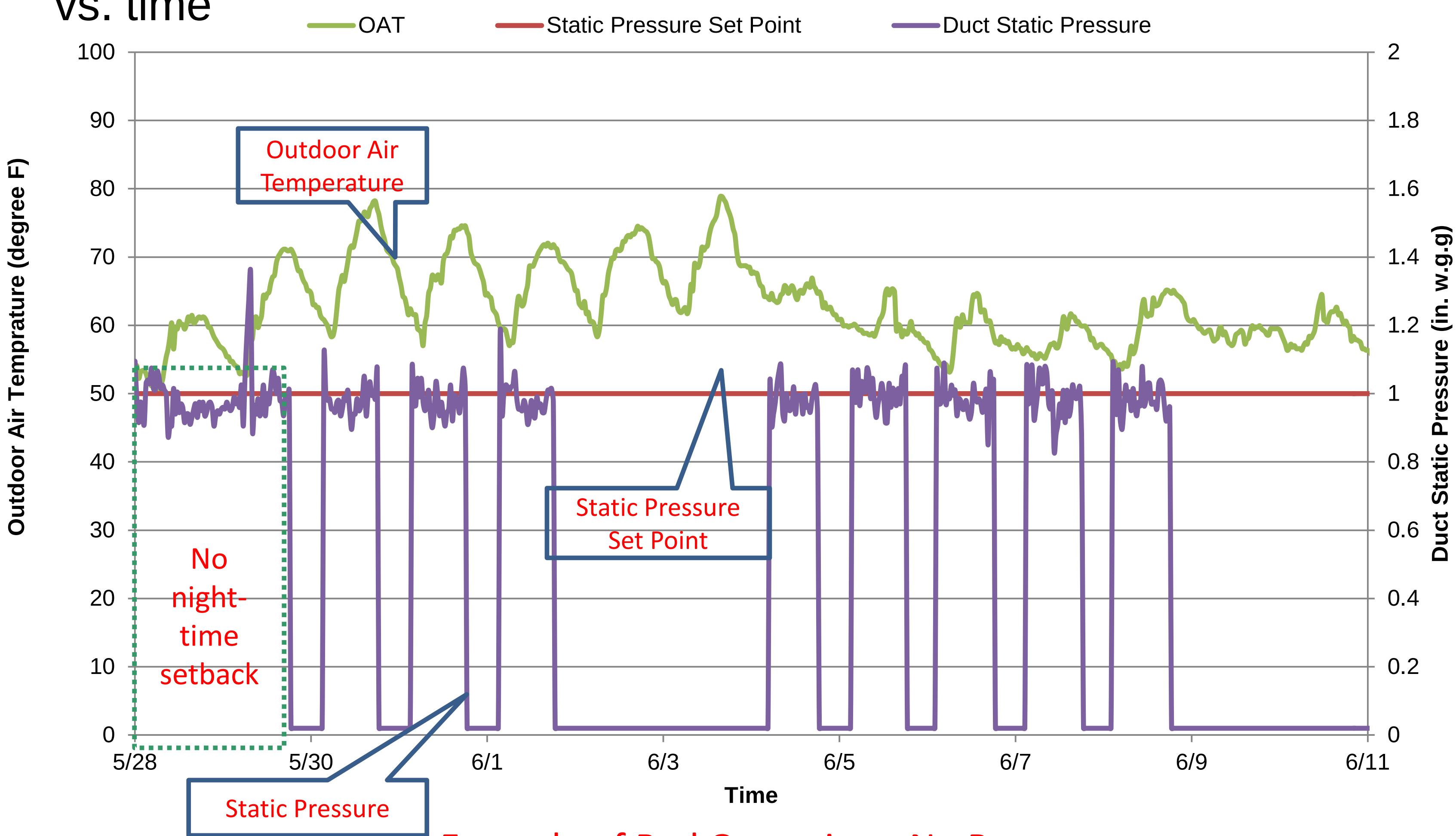
- Duct static pressure and set point vs. time



Example of Bad Operation - No Reset

No Static Pressure Reset: Example of Bad Operation

- Duct static pressure and set point, and outdoor-air temperature vs. time



Example of Bad Operation - No Reset

Air-Handler Data Analysis: Heating and Cooling

- Pre-Re-Tuning Phase:
  - Air-Handling Units: Trend-data collection and analysis of heating and cooling

- Re-tuning Phase:
  - Air-Handling Units: Heating and cooling

Air-Handler: Heating and Cooling

- Are the heating and cooling coils efficient?
  - Clean
  - Valves not leaking through
    - Check (touch) coil for temperature of pipes at air-handler penetrations
      - Should be room temperature, if not active
  - Loops locked out at some outdoor-air temperature preventing heating and cooling at same time
    - Heating locked out above 50ºF or lowest temperature building can do without heat
    - Cooling locked out below 55ºFor highest temperature building can do without cooling
    - Critical on dual-duct and multi-zone systems
- Balance point of building is critical when setting these lockouts

Air-Handler: Heating and Cooling (continued)

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- Trended data for discharge-air temperatures that show sharply falling temperatures well below set point that are coincidental to the chiller system starting and remain well below set point are indicative of a failed (leaking) cooling control valve
- Trended data for discharge-air temperatures that show sharply rising temperatures well above set point that are coincidental to the boiler/reheat system starting and remain well above set point are indicative of a failed (leaking) heating control valve
- Trended data for discharge-air temperature that shows a heating valve open to maintain discharge-air set point with the economizer control on full re-circulation (or minimum outside air) and a mixed-air temperature that is above the discharge-air temperature, is indicative of a leaking chilled water valve (if the chiller system is active)
- If condensate is observed on un-insulated lines or exposed coil sections during times when mechanical cooling is not being called for by the control system or during times when outside-air temperature should be adequate for “free” cooling, then leaking cooling control valves should be suspected
- If heating and cooling loops come with outside-air temperature lockouts, but those lockout settings are set to abnormal values, this would indicate failed or leaking control valves that indicate simultaneous heating and cooling (energy intensive)

Air-Handling Unit: Outdoor-air Lockouts for Heating and Cooling

- Purpose: Determine whether the outdoor-air lockouts for heating and cooling are set to reasonable values
- Approach:
  - Use plots of heating and cooling set points vs. time to determine whether lockouts are set backwards – cooling lockout is lower than the heating lockout
  - Use plots of heating and cooling valve positions to determine whether heating and cooling of the air stream are taking place at the same time

Air-Handling Unit: Outdoor-Air Lockouts for Heating & Cooling (continued)

- Potential issues to identify
  - Air-handler heating and cooling coils operating simultaneously
  - Heating and cooling lockouts possibly overlapping (need to be confirmed in control-code settings during on-site re-tuning)
  - Unreasonable values are set for the heating and cooling lockouts

Outdoor-Air Lockouts for Heating and Cooling: Example use of Graphs

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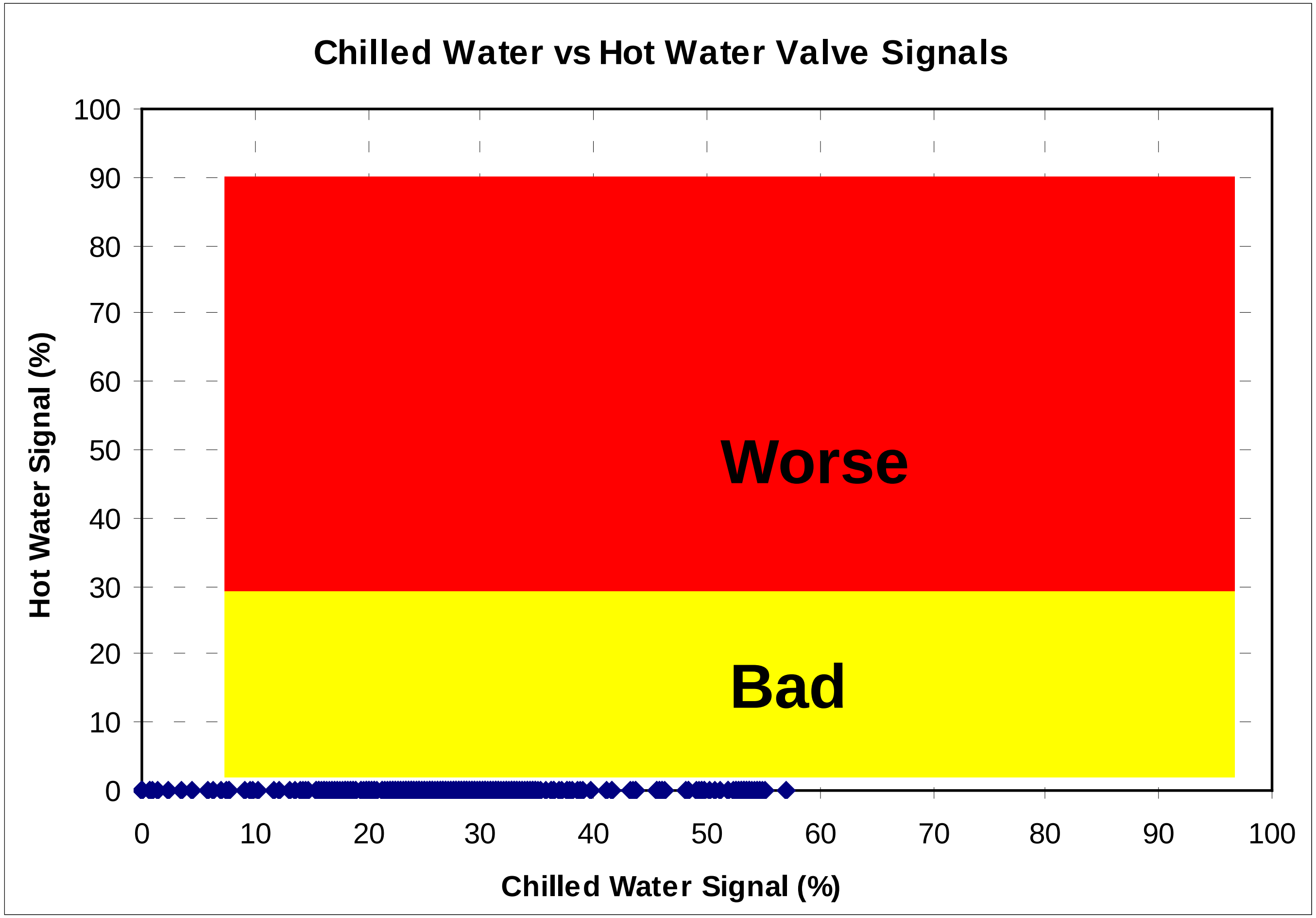
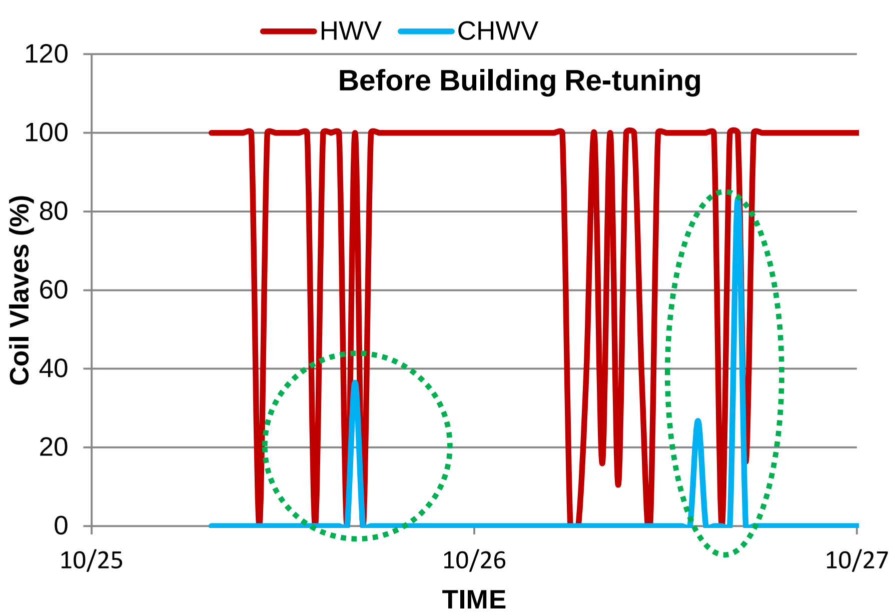
- Air-handler heating vs. cooling valve positions

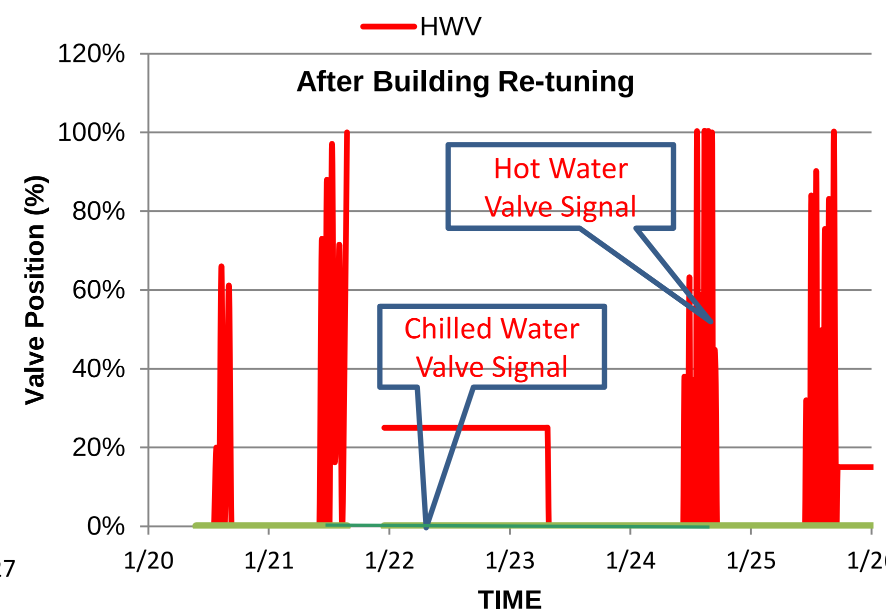


Lockout for Cooling During Winter Season: Before and after Building Re-tuning

- Heating coil valves and cooling coil valve signals vs. time



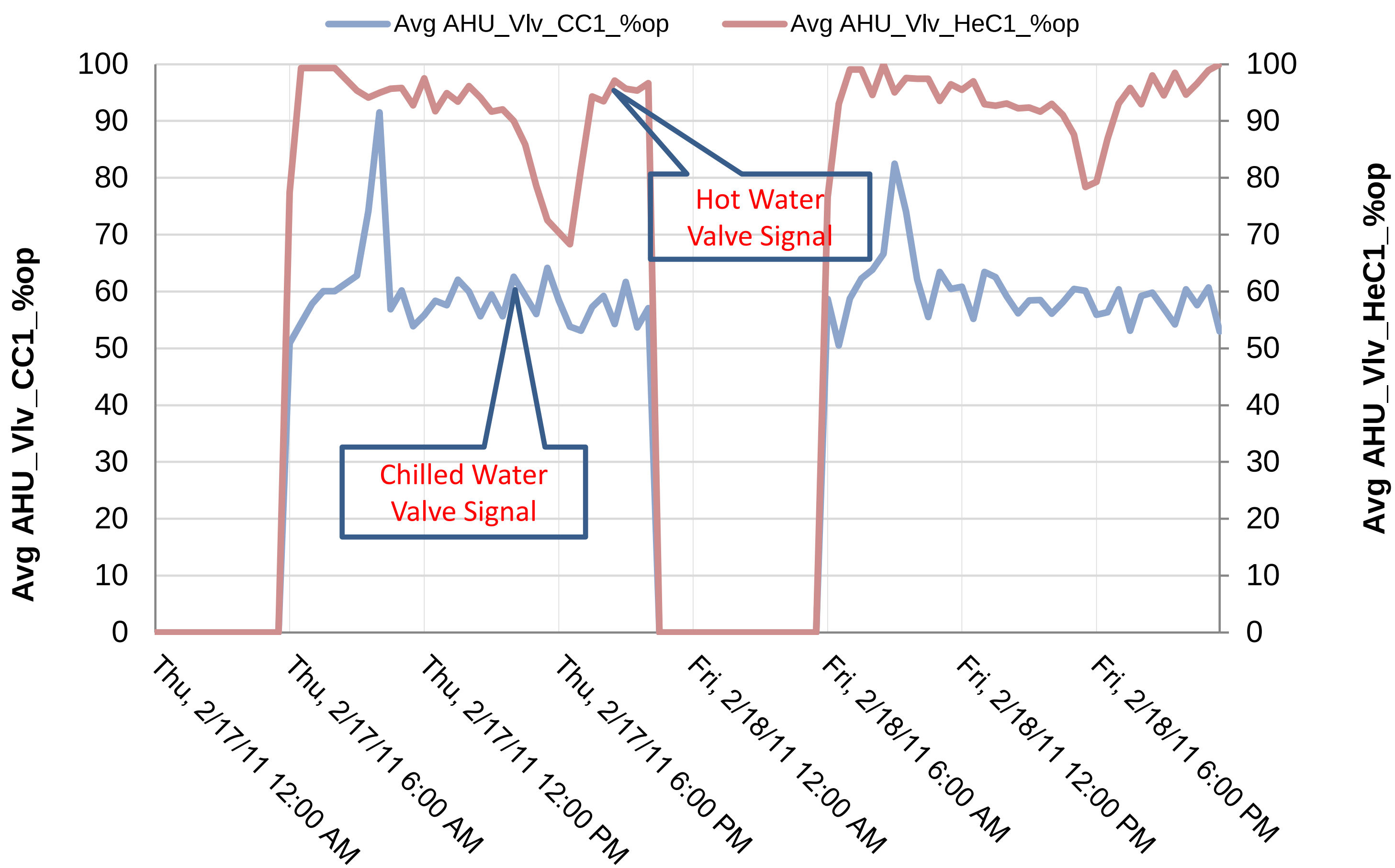
Example of Bad Operation



Example of Good Operation

Example of Simultaneous Heating and Cooling: Bad Operation

- Heating and cooling coil valve signal vs. time



Example of Bad Operation

Example of Simultaneous Heating and Cooling: Bad Operation

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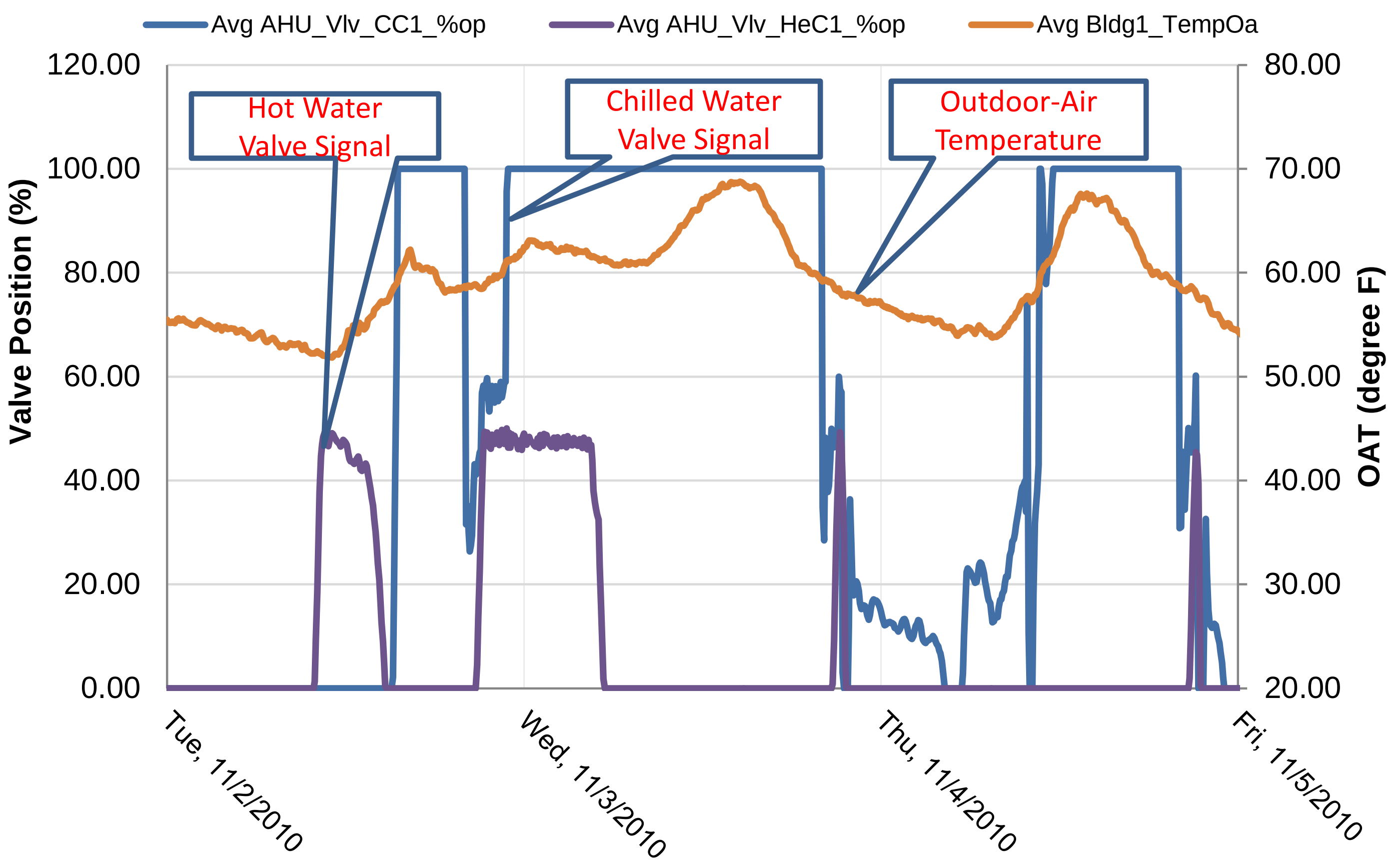
- Heating and cooling coil valve signal, and outdoor-air temperature vs. time



Example of Bad Operation

Example of Simultaneous Heating and Cooling: Bad Operation

Pacific Northwest NATIONAL LABORATORY
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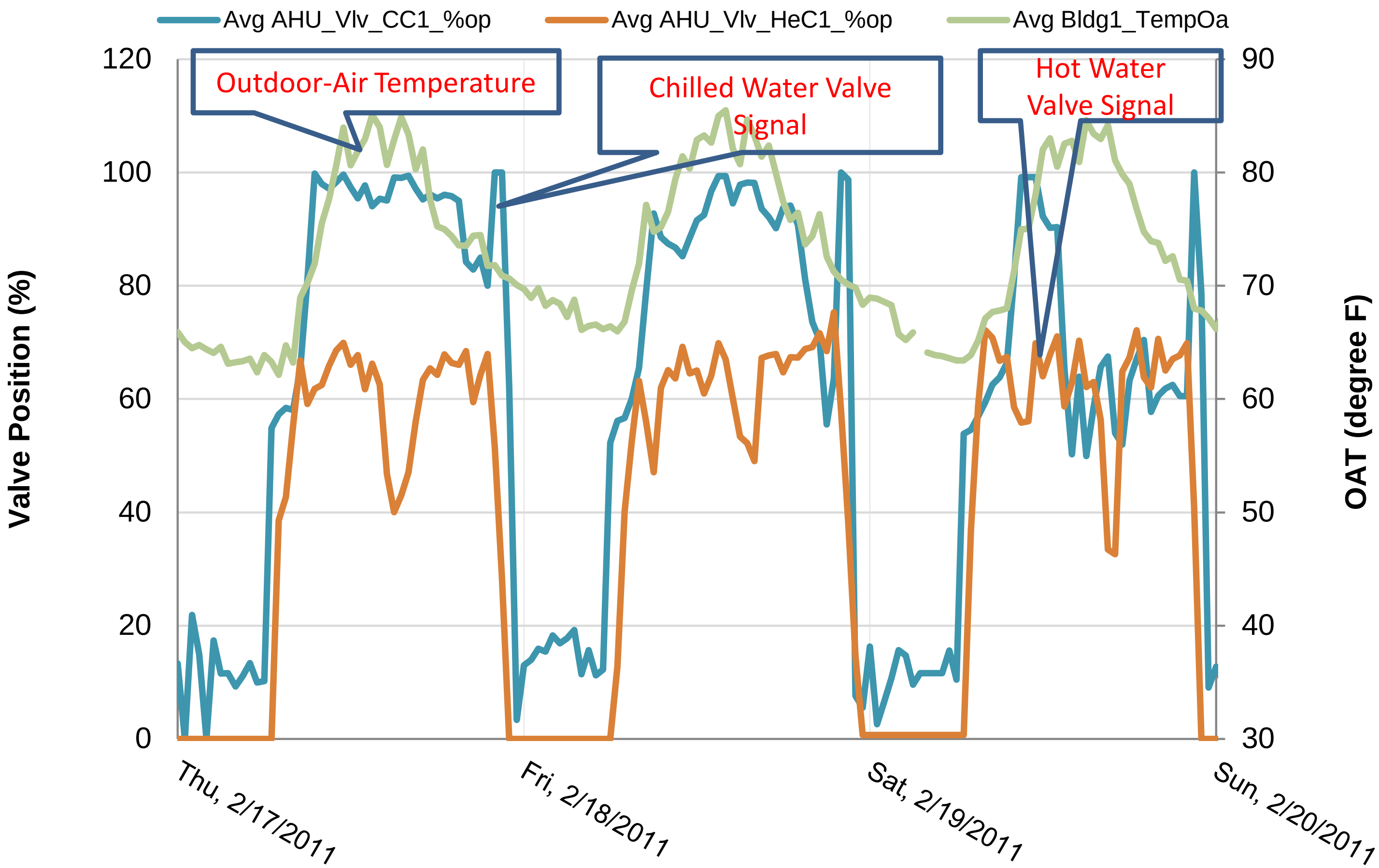
- Heating and cooling coil valve signals, and outdoor-air temperature vs. time



Example of Bad Operation

Air-Handling Unit: Minimum Outdoor-Air

- Pre-Re-Tuning Phase:
  - Air-Handling Units: Trend-data collection and analysis of minimum outdoor air

- Re-tuning Phase:
  - Air-Handling Units: Minimum outdoor air operations

Air-Handling Unit: Minimum Outdoor-Air Operations

- Purpose
  - Review minimum outdoor-air operations
  - Determine whether sufficient outdoor-air is being supplied for ventilation
  - Determine whether more outdoor-air than needed is being brought in at times (e.g., when the outdoor-air temperature < 40°F or > 60°F or when the zones served are unoccupied)
  - Determine whether outdoor-air dampers close during night and weekend set back and during startup mode in the morning

Air-Handling Unit: Minimum Outdoor-Air Operations (continued)

- Approach
  - For each air-handling unit with air-side economizer, review plots:
    - Outdoor-air fraction (OAF) vs. time
    - Outdoor-air damper and occupancy mode vs. time
    - Outdoor-air fraction vs. fan speed (if available)
  - Determine if OAF > minimum OAF for ventilation when the system is not economizing
  - Determine whether outdoor-air ventilation is being provided when the building is unoccupied and ventilation is not required for some other reason, especially when in the heating mode and when conditions are not favorable of economizing in cooling mode
  - If OAF and fan speed are tracking each other, it is an indication of return-air problems
  - **20% damper position is never 20% outdoor air**

Air-Handling Unit: Minimum Outdoor-Air Operations (continued)

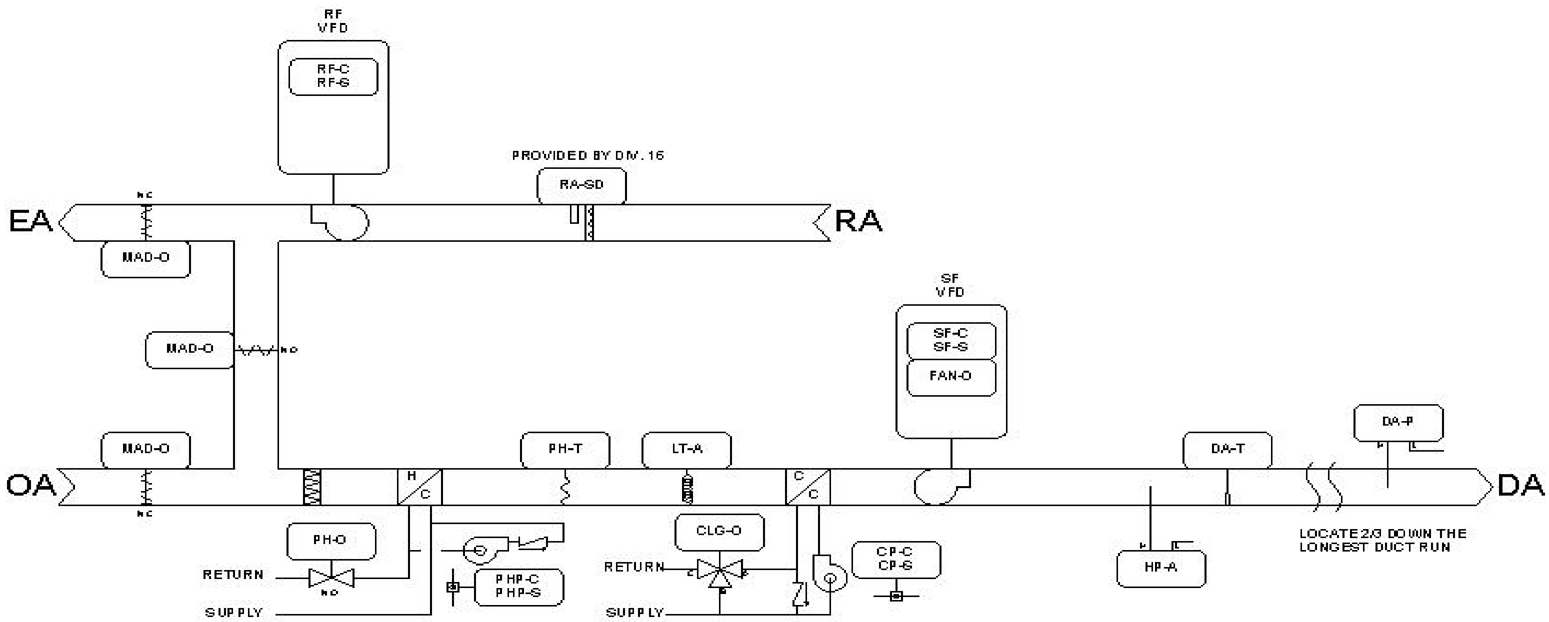
- Potential issues to identify
  - Insufficient outdoor-air ventilation provided – minimum outdoor-air fraction (OAF) is too low
  - Too much outdoor-air ventilation provided when the air-handler is not economizing
  - Too much outdoor-air ventilation provided during unoccupied times (nights and weekends, during set back)
- Use air fraction to find % of outdoor-air
  - Works if air is mixed relatively evenly
  - OAF = ((Return-Mixed)/(Return-Outdoor))*100
  - Add into code for all air handlers and track history
    - Especially schools and other public spaces
- Use CO_2 sensors whenever possible for areas with changing staff loads and larger spaces (conference rooms, auditoriums, etc)
  - Infiltration may satisfy ventilation needs without outdoor-air dampers being open

Air-Handling Unit: Outdoor-Air Makeup (continued)

- Does your DDC system have separate outdoor-, return- and mixed-air temperature sensors?
- Does your DDC system use these values to calculate outdoor-air fractions?

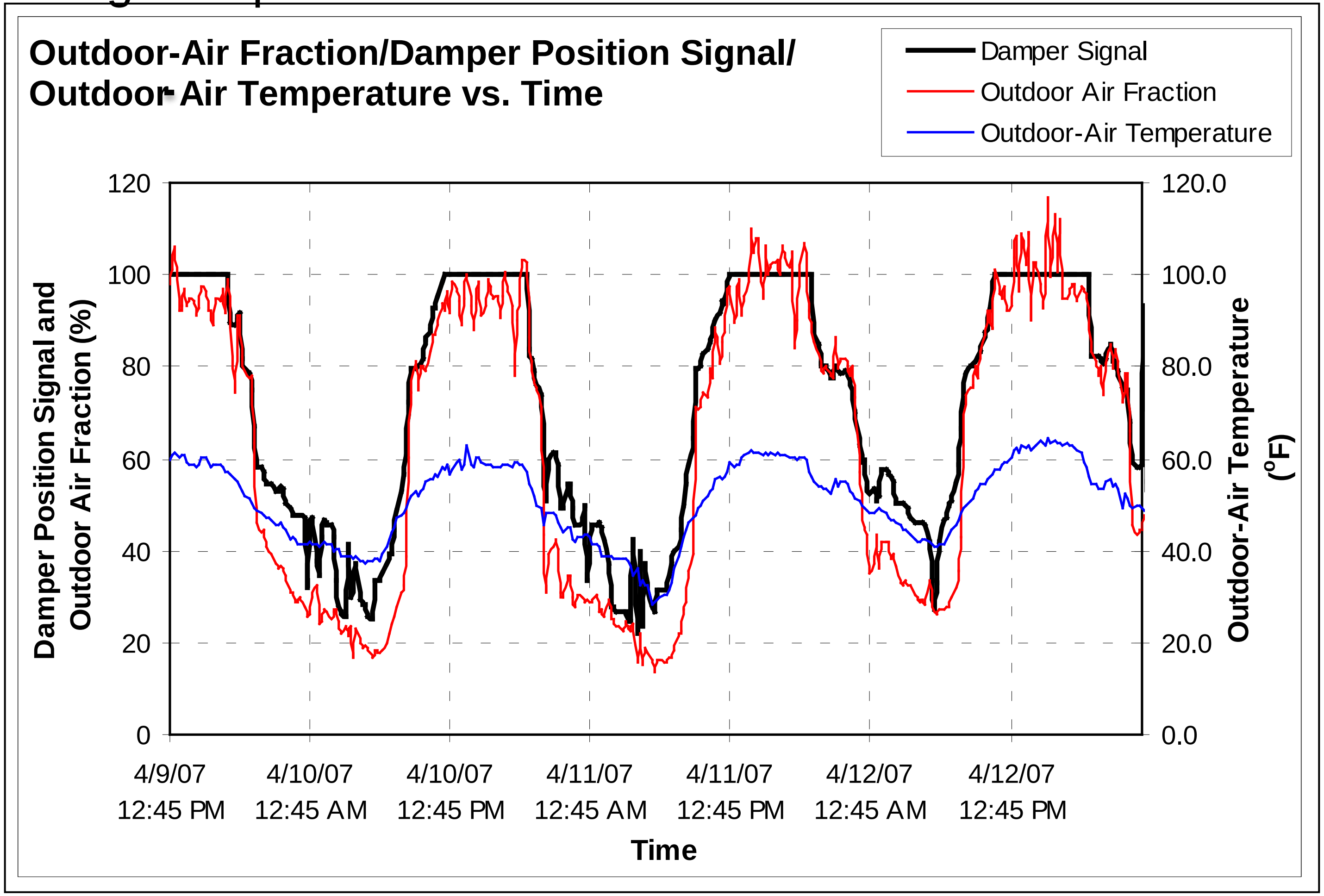
Air-Handling Unit: Outdoor-Air Makeup

- 20% damper is never 20% air flow
- Pressure differential across outdoor-air damper is more important than damper position
- No pressure differential leads to no flow
- High delta leads to high flow



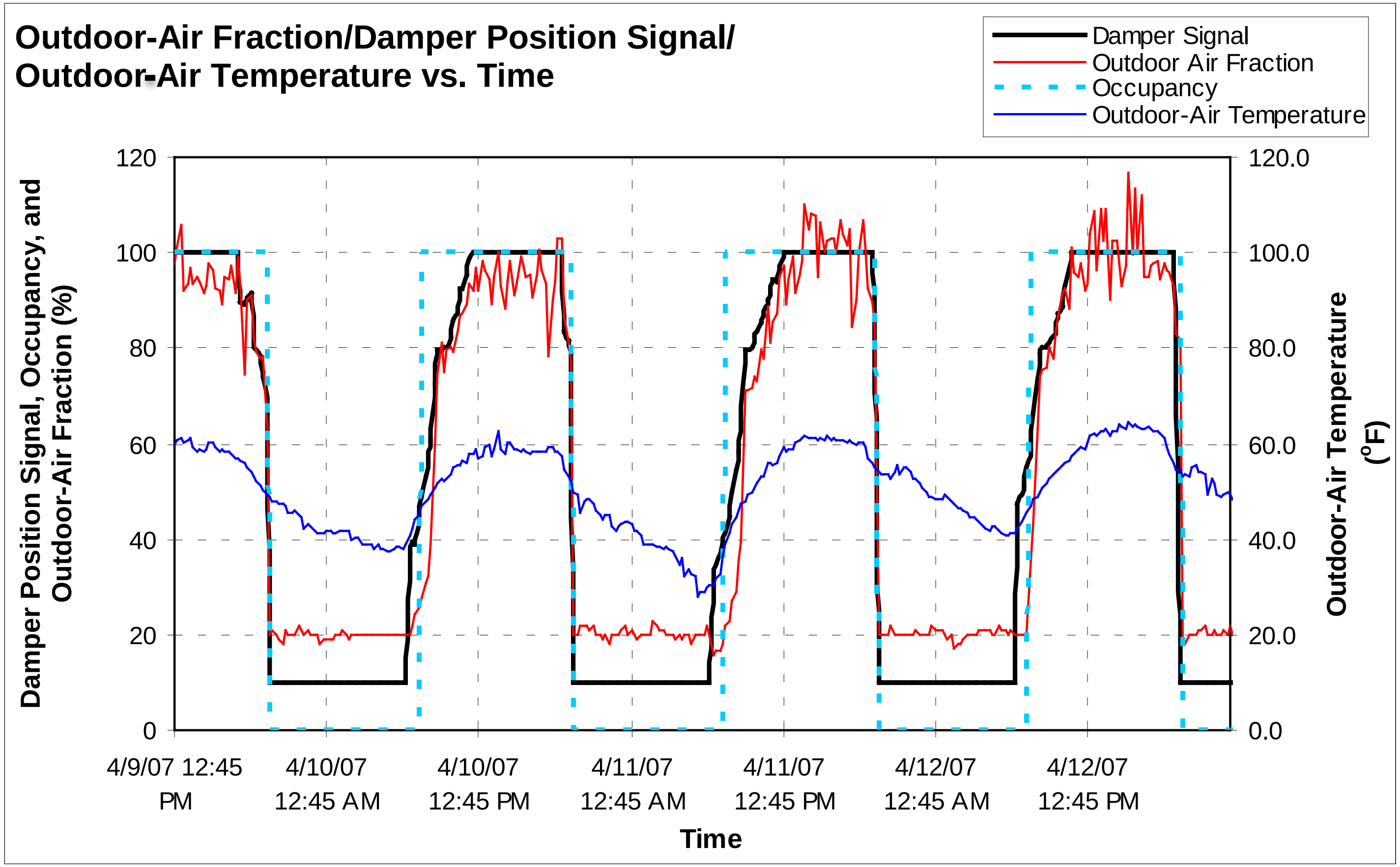
Air-Handling Unit: Minimum Outdoor-Air Operations: Example use of Graphs

- Outdoor-air fraction and temperature, and damper position vs. time: building occupied 24/7



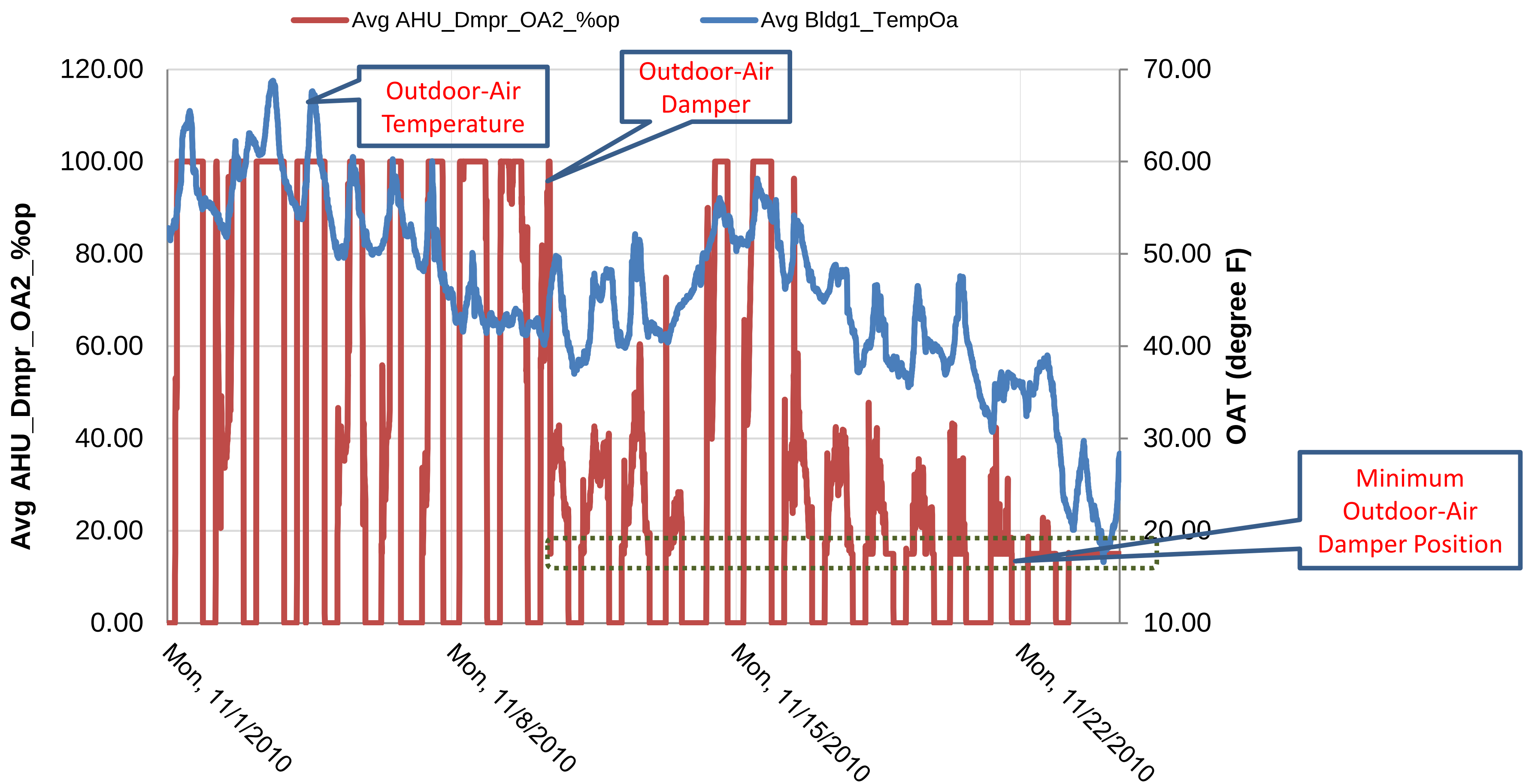
Air-Handling Unit: Minimum Outdoor-Air Operations: Example use of Graphs

- Outdoor-air fraction and temperature, and damper position vs. time: building occupied 12 h/d



Air-Handling Unit: Minimum Outdoor-Air Operations: Normal Operation

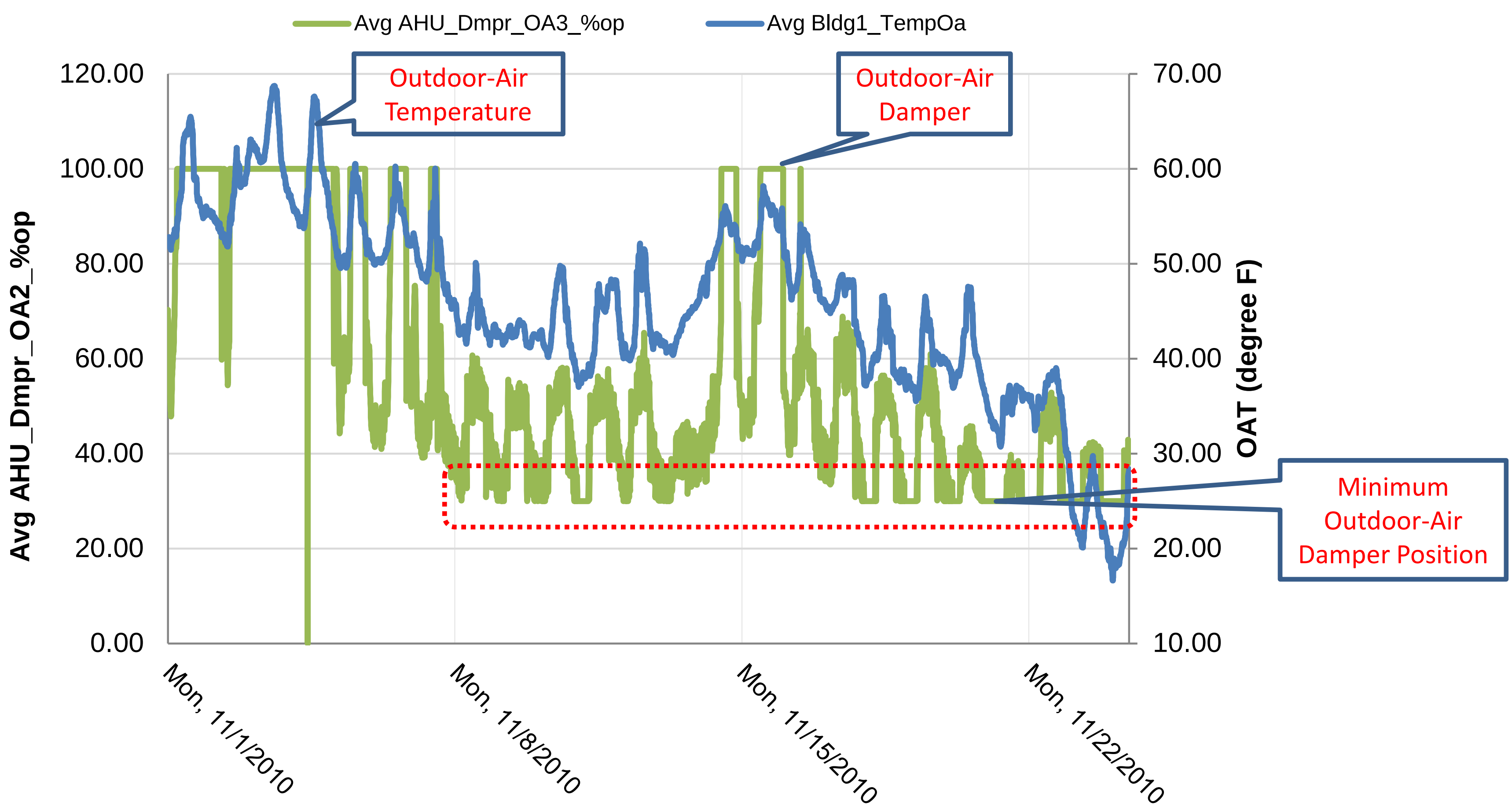
- Outdoor-air damper vs. time



Minimum Outdoor-Air Damper Position = 15%

Air-Handling Unit: High Minimum Outdoor-Air Damper Position

- Outdoor-air damper vs. time



High Minimum Outdoor-Air Damper Position = 30%

QUESTIONS?

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