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BAS Control of VAV Labs

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Controls for variable air volume (VAV) laboratory supply and exhaust systems have traditionally been separate from the primary building automation system (BAS). This was necessary in the early days of VAV labs when the control systems were analog and/or pneumatic, but it has continued even after these systems converted to modern digital control systems in the late 1990s. The controls have typically been marketed and sold as a package along with the air valves (VAV damper systems) used for supply and exhaust airflow modulation. This typically results in two separate control systems: the lab controls for labs and the BAS for everything else, including non-lab zones, air handlers, heating and cooling plant, etc. In this month's column, I will discuss how to use the BAS to do all controls, allowing dedicated lab controls to be eliminated.

This column focuses on VAV systems with hot water reheat because it is the most popular lab HVAC system design. In a future column, I will discuss an enhanced design that includes both heating and cooling at the zone level, a design that can completely eliminate reheat energy losses.

Problems with Dedicated Lab Controls

Disadvantages of having both dedicated lab controls and a separate BAS include:

- Higher costs for two systems. The lab controls and the BAS can each have their own networks, controllers, software, servers, user interfaces, etc., often overlapping and redundant. Labor costs for installation, start-up, commissioning, and training are also at least partly duplicated. In some designs, even the labs have both systems: the lab controls for airflow management and the BAS for temperature control, resulting in almost double the control system costs.
- Higher costs due to limited competition. Lab controls and their associated air valves are heavily marketed by the manufacturers and their sales representatives, targeting both lab users and lab designers. Many are successful in being sole-sourced on company or university campuses, eliminating competitive pricing. Usually their monopoly is due to the unique design of their air valves (discussed more below), not the controls, but the controls are sold with the valves as a package, so neither is competitively priced.
- Hood monitor coordination and installation. Hood monitors are required by code to monitor hood face velocity and provide alarms if velocity is below a minimum setpoint. For constant air volume (CAV) hoods, monitors are usually provided factory installed with the hood (Division 11). But, with VAV hoods, a gray area exists that must be coordinated among the design team. Some VAV lab hood controls require the monitor be a part of the lab controls; for most others, the monitor is offered but is optional. When the monitors are provided with the controls, they are almost always field installed, which is more costly than factory installation. If CAV hood monitors are factory installed with the hood, and VAV hood monitors are field installed by the lab control contractor, the monitors will differ in style and function. Therefore, users must be trained for both.
- Contractor coordination. Typically, the lab controls subcontractor is different from the subcontractor providing and installing the BAS, and their work and

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scheduling must be coordinated and managed. Having one contractor holding up the other near completion is common.

- Integration problems. Systems that mix lab and BAS controls at the zone level in particular are susceptible to problems with controller and control logic integration and tuning. But even systems interconnected only at the Internet Protocol (IP) level can have issues passing information (such as damper position and zone demand used for setpoint reset) back and forth in a robust enough manner that control is stable.
- Building engineer training. Two systems means two user interfaces, two programming languages, multiple controller types, etc. Building operators have enough trouble becoming conversant with one complex digital control system; having two systems significantly reduces the likelihood of well-trained operators.

Advantages of dedicated lab controls include:

- The control logic is largely "canned" in the lab controllers so that it need not be programmed for each project.
- The technicians doing the start-up and commissioning are usually more experienced with lab-related systems (lab air valves, hoods, etc.) than typical BAS contractors.

These are a significant advantages now, but over time they will fade as sequences become standardized (see "Laboratory VAV Reheat Zone Sequence of Operation") and as BAS contractors develop lab expertise.

VAV Fume Hoods

First, a brief discussion of variable air volume fume hoods and their controls is provided because they can play a part in the design of the controls. VAV hoods include adjustable sashes that vary the required exhaust rate. Two technologies are required to control the hood exhaust system in response to varying sash position:

- Devices to determine the exhaust airflow setpoint needed to maintain the desired hood inlet (face) velocity setpoint, typically 100 fpm (0.5 m/s). The most common design uses sash position sensors to determine sash

Laboratory VAV Reheat Zone Sequence of Operation

This Control Logic Applies to Both "Fast" and "Slow" Labs (*Figures 2* and *3*).

A. Information Scheduled on Drawings

1. Design setpoints shall be as scheduled on plans:

a. Room schedule

1) Pressurization offset (V_{offset}). Initial pressurization offsets shall be shown on schedules. For some zones, final pressurization offsets shall be determined as specified under Section 230593 Testing, Adjusting, and Balancing.

b. Supply air valve

1) Maximum airflow setpoint (V_{max})

2) Minimum occupied airflow setpoint ($V_{min\text{-}occ}$)

3) Minimum unoccupied airflow setpoint ($V_{min\text{-}unocc}$)

4) Design heating coil leaving air temperature (SAT_{max})

c. Hood exhaust (HEX) air valve. Where there is more than one hood (see plan for quantity), rates shall be added together.

1) Maximum airflow setpoint ($V_{hex\text{-}max}$)

2) Minimum airflow setpoint ($V_{hex\text{-}min}$)

d. General exhaust (GEX) air valve. Where there is more than one GEX (see plan for quantity), rates shall be added together.

1) Maximum airflow setpoint ($V_{gex\text{-}max}$)

2) Minimum airflow setpoint ($V_{gex\text{-}min}$)

2. Controllable minimum. Where there is more than one terminal, rates shall be added together.

a. Supply controllable minimum ($V_{ctrl\text{-}min}$)

b. General exhaust controllable minimum ($V_{gex\text{-}ctrl\text{-}min}$)

B. Sequences of Operation

1. The actual minimum V^*_{min} shall be equal to the larger of:

a. Exhaust makeup air rate calculated below, V_{mu}

b. Minimum ventilation rate (V_{vent}) equal to:

1) If the zone is unoccupied as indicated by its occupancy sensor <u>and</u> the lab is scheduled to be unoccupied, $V_{min\text{-}unocc}$

2) Otherwise, $V_{min\text{-}occ}$

c. $V_{ctrl\text{-}min}$

2. Supply air system

a. Supply airflow and temperature control logic is depicted schematically in *Figure 1* and described in the following sections.

b. When the zone is in the cooling mode, the cooling loop output shall be mapped to the airflow setpoint from $V_{cool\text{-}max}$ at 100% cooling loop down to V^*_{min} at 0% cooling loop output.

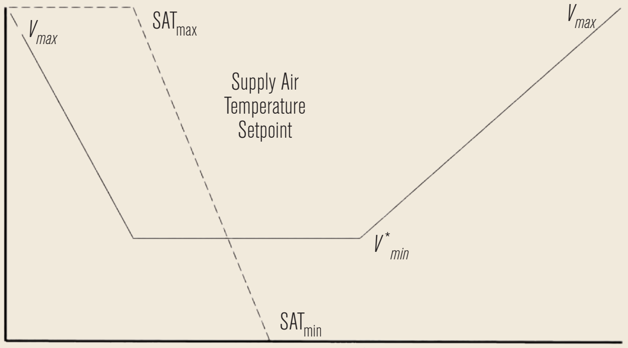

FIGURE 1 Airflow and temperature setpoint control diagram.

c. When the zone is in the deadband mode, the airflow setpoint shall be V^*_{min}

d. When the zone is in the heating mode:

1) Supply air temperature setpoint shall be reset from deadband SAT_{min} at 0% heating loop output proportionally up to SAT_{max} at 50% heating loop output and above. SAT_{min} shall be 55°F (13°C) unless otherwise indicated on drawings.

2) If the supply air temperature is greater than the room temperature plus 5°F (2.8°C), the airflow setpoint shall be reset from V^*_{min} at 50% heating loop output and below proportionally up to V_{max} at 100% heating loop output.

e. The hot water valve shall be modulated using proportional plus integral loop to maintain the discharge temperature at setpoint. (Directly controlling the HW valve off the zone temperature PID loop is not acceptable.)

f. The VAV damper shall be modulated to maintain the measured airflow at setpoint.

3. Pressurization control

a. Sign conventions: All airflows have a positive sign, except for the room offset airflow, which may be positive (for positively pressurized lab) or negative (for negatively pressurized lab).

b. $V_{gex\text{-}step}$ shall be equal to $V_{gex\text{-}ctrl\text{-}min}$

1) Exception: $V_{gex\text{-}step}$ shall equal 0 if supply airflow setpoint is equal to V^*_{min} and the following has been less than or equal to 0 for 30 seconds or more:

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*Active minimum setpoint.

opening. Another technology measures velocity pressure through the hood enclosure to infer face velocity, the same technology commonly used for hood monitor alarms.

- Air valves to control hood exhaust airflow at setpoint. There are two basic air valve designs: closed loop systems that measure airflow and modulate the air valve damper with a control loop to maintain setpoint (similar to a standard VAV box), and inherently pressure independent air valves that adjust for changes in duct system pressure using springs and the shape of the valve (e.g., venturi) and damper.

      a) The larger of V_{vent} and $V_{ctrl\text{-}min}$, minus the sum of:
         1. Sum of fume hood exhaust valve(s) airflow feedback;
         2. Other exhaust airflows, e.g., canopy/cabinet/snorkel, etc. (if applicable, see plans for quantity and airflows); and
         3. V_{offset}
   c. The makeup airflow demand (V_{mu}) is equal to the sum of:
      1) Sum of fume hood exhaust valve(s) airflow feedback;
      2) $V_{gex\text{-}step}$
      3) Other exhaust airflows, e.g., canopy/cabinet/snorkel, etc. (if applicable, see plans for quantity and airflows); and
      4) V_{offset}
   d. The general exhaust valve setpoint shall equal 0 when $V_{gex\text{-}step}$ is equal to 0. Otherwise, it shall equal the sum of:
      1) Supply valve feedback airflow minus V_{mu}; and
      2) The general exhaust valve controllable minimum airflow, $V_{gex\text{-}ctrl\text{-}min}$

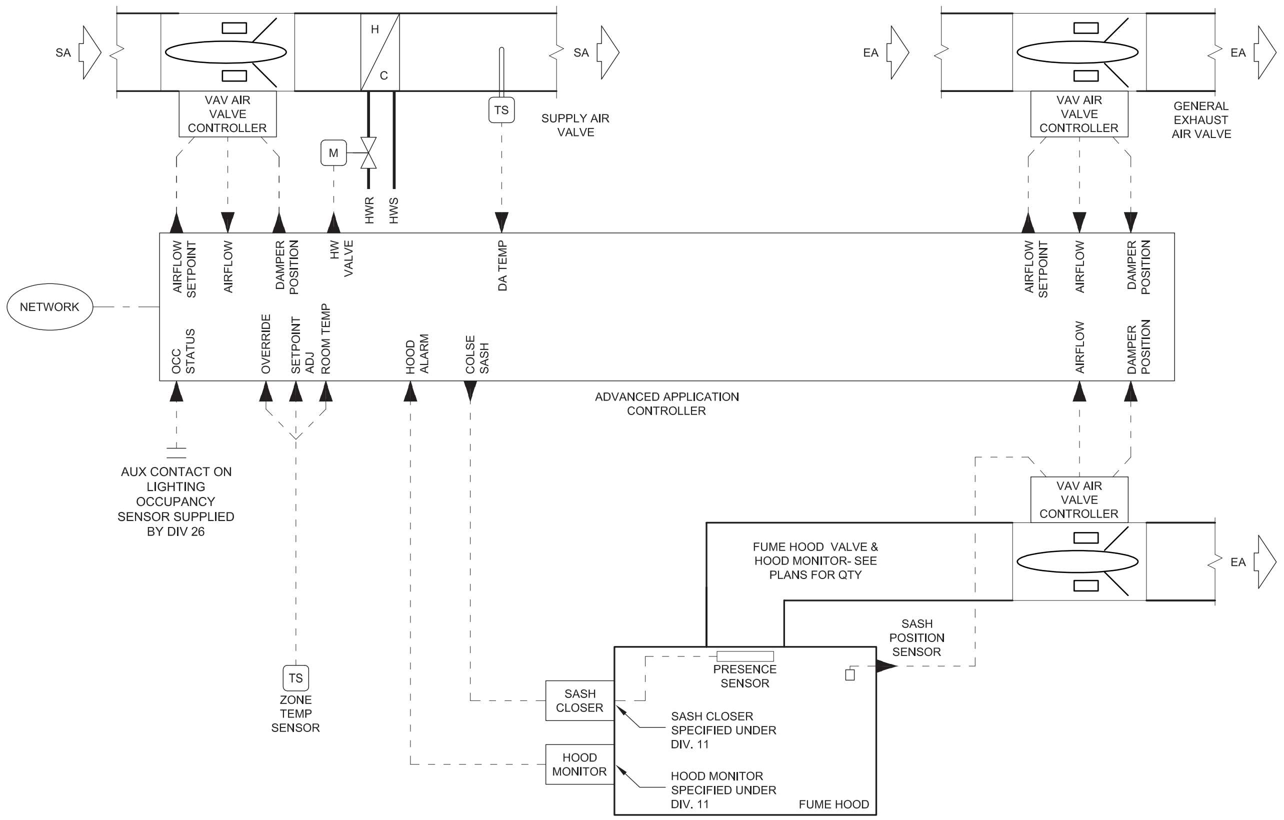
4. Command sash closers to close on all hoods in room:
   a. If the supply air fan(s) in the AHU serving this zone are proven off; or
   b. If supply airflow to zone is less than 75% of setpoint.
5. Alarms
   a. Airflow alarm
      1) If the airflow feedback from any valve is 15% above or below setpoint for 5 minutes, generate a Level 3 alarm.
      2) If the airflow feedback from any valve is 30% above or below setpoint for 5 minutes, generate a Level 2 alarm.
   b. Room pressurization polarity alarm
      1) Generate a Level 2 alarm if the airflow offset has incorrect polarity for 5 minutes based on sum of exhaust feedback signals and supply feedback signal:
         a) For a room with negative offset, if exhaust minus supply < 0
         b) For a room with positive offset, if exhaust minus supply > 0
   c. Room low supply rate alarm
      1) If the sum of exhaust feedback signals exceeds the supply feedback signal by more than four times (adjustable) the offset for one minute:
         a) Generate a Level 1 alarm (high level due to problems exiting).
         b) All fume hood sashes in room shall be commanded closed.
         c) All fume hood exhaust setpoints shall be reduced to a fixed percentage of the maximum hood rates; this percentage shall be determined as specified in Section 230593 Testing, Adjusting and Balancing.
   d. Low supply air temperature
      1) If boiler plant is proven on and the supply air temperature is 15°F (8.3°C) less than setpoint for 10 minutes, generate a Level 3 alarm.
      2) If boiler plant is proven on and the supply air temperature is 30°F (16.7°C) less than setpoint for 10 minutes, generate a Level 2 alarm.
   e. Fume hood
      1) Fume hood alarm: Level 2
      2) If average sash height during the last 24 hours is greater than 50% (adjustable), generate a Level 4 alarm.

See ASHRAE RP-1455[4] and ASHRAE Guideline 36P[5] for How "Requests" are Used in Trim and Respond Reset Logic.

6. System requests
   a. Cooling SAT reset requests
      1) If the cooling loop is less than 85%, send zero requests.
      2) If the cooling loop is greater than 95%, send one request.
      3) If the zone temperature exceeds the zone's cooling setpoint by 3°F (1.7°C) for two minutes, send two requests.
      4) If the zone temperature exceeds the zone's cooling setpoint by 5°F (2.8°C) for two minutes, send three requests.
   b. Exhaust or supply static pressure reset requests (venturi type valves; separately include all exhaust and supply air valves in zone)
      1) If the supply valve differential pressure is greater than 0.35 in. w.g. (87.2 Pa), send zero requests.
      2) If the supply valve differential pressure is less than 0.3 in. w.g. (74.7 Pa) for 30 seconds, send one request.
      3) If the supply valve differential pressure is less than 0.25 in. w.g. (62.3 Pa) for 30 seconds, send three requests.
   c. Exhaust or supply static pressure reset requests (feedback loop type valves; separately include all exhaust and supply air valves in zone)
      1) If the damper loop is less than 85%, send zero requests.
      2) If the damper loop is greater than 95%, send one request.
      3) If the measured airflow is less than 85% of setpoint for 30 seconds, send three requests.
   d. Heating HWST reset requests
      1) If the HW valve is less than 85%, send zero requests.
      2) If the HW valve is greater than 95%, send 1 request.
      3) If the supply air temperature is 15°F (8.3°C) less than setpoint for five minutes, send two requests.
      4) If the supply air temperature is 30°F (16.7°C) less than setpoint for five minutes, send three requests.
   e. Boiler plant requests. Send the boiler plant that serves the zone a boiler plant request as follows:
      1) If the HW valve is less than 10%, send zero requests.
      2) If the HW valve is greater than 95%, send one request.

Within these two technologies there are many variations, such as various devices for measuring airflow and various damper designs, including pneumatic bladders. In all cases, the controls have to be fast-acting and very robust—they have to be able to react immediately to a sash being thrown open or closed and reach stable control within a few seconds.

There are strong (sometimes fervently strong) proponents and detractors of each of the above designs, which can result in sole-sourcing, as mentioned above. But one of the advantages of the control system design outlined in this column is that it is agnostic to air valve



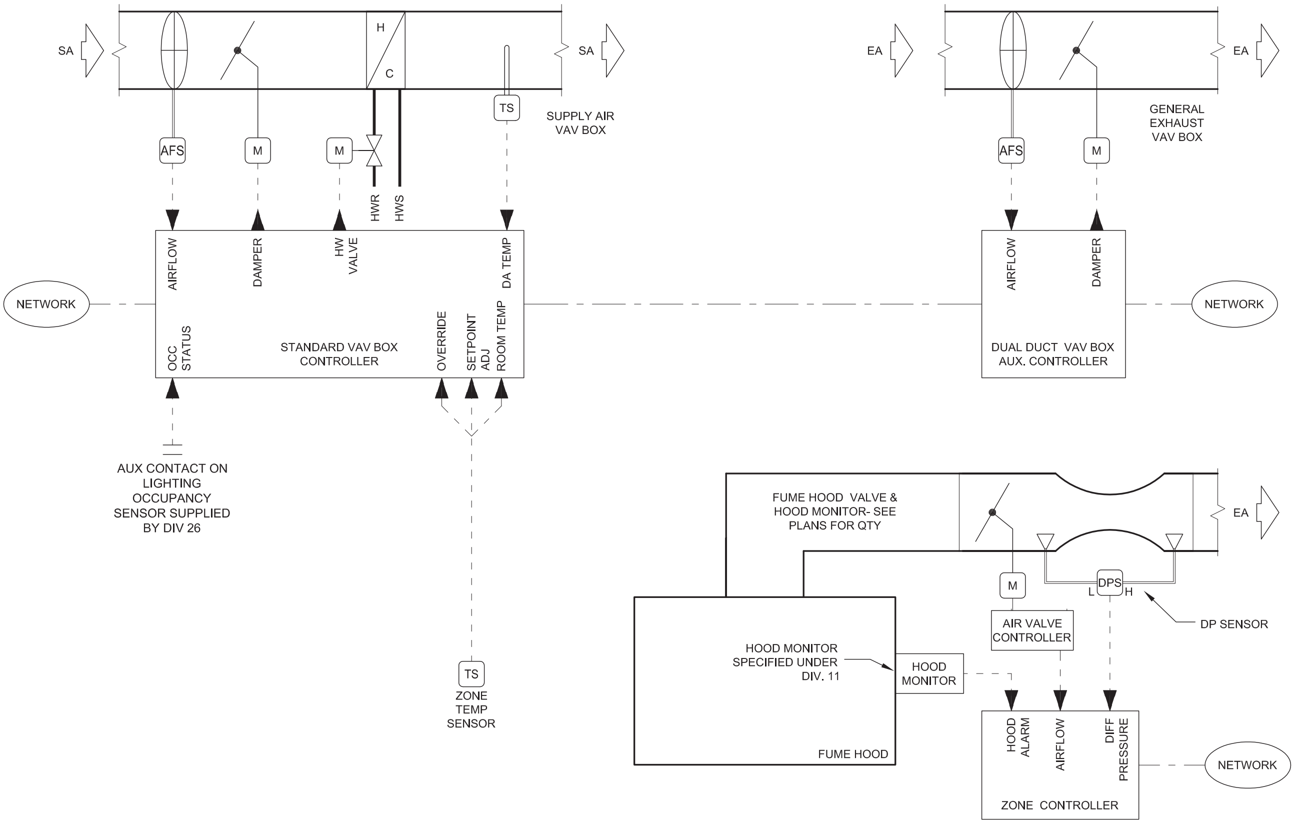


FIGURE 2 (TOP) "Fast" lab control schematic. FIGURE 3 (BOTTOM) "Slow" lab control schematic.

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design; any design can be used with no significant impact on the design of the overall control system. Thus, the supplier of the fume hood controls and air valves can be completely different from the control system vendor. The air valve and sash sensing technology can be sole-sourced, if the owner (or engineer) insists, while still getting competitive pricing on the remainder of the controls.

"Fast" Lab Control

"Fast" labs are those that are fume hood dominated, meaning the hood exhaust rates exceed the rates required for both temperature control (cooling) and for minimum dilution ventilation. In fast labs, most or all the hoods are the variable air volume type discussed above. The term "fast" comes from the fact that the fume hoods have fast-acting controls, as described above. This means the supply air and general exhaust air valves also must be lab type, fast-acting air valves.

Figure 2 (Page 58) shows "Fast" lab controls using BAS controls. Features of the design include:

- A single controller is used to control the entire lab, rather than using multiple networked controllers. This is done to ensure that network traffic issues do not affect the speed and stability of control response. As noted above, the system must respond and stabilize in seconds. The controller typically is a BACnet[1] advanced application controller (AAC) depending on the control system manufacturer's point count capability. If the AAC does not have enough points, as would be the case if the lab has many hoods, "slow" points (those that are not part

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of the airflow control loops, such as damper position feedback, alarms, etc.), may be moved to separate controllers. Some air valve manufacturers have BACnet master-slave/token passing (MS/TP) network connections on their controllers, which allow "slow" points to be transferred via the network rather than hardwired to the controller.

For labs with many hoods, a BACnet Building Controller may be needed to handle the point count; these controllers can reside on the IP network, rather than the MS/TP network, for improved data transfer speed to the control system server. Note that many dedicated lab controls use Lon[2] or MS/TP networks to transfer information between lab air valves—they do not use a single controller as shown in *Figure 2*—but these are networks dedicated to this purpose so speed is more predictable. Nevertheless, using a single controller is one of the advantages of this control system design.

- The air valves shown in *Figure 2* are closed-loop type. (The example in *Figure 3,* Page 58, discusses venturi type air valves.) But, any air valve manufacturer can be used; the only requirement is that the valve controller include an input for airflow setpoint, an output for actual airflow, an output indicating damper position, and the ability to quickly and stably adjust damper position to meet rapid changes in airflow setpoint. Damper position is used to reset exhaust fan inlet static pressure setpoint as required by ASHRAE Standard 90.1[3] in all versions since 2004. Even if stack exhaust rates are constant, e.g., to meet equivalent stack height requirements, fan energy is significantly reduced if inlet static pressure setpoint is reduced to that required by the most demanding valve.
- Occupancy status is monitored via the lighting control occupancy sensor. This optional feature allows setback of minimum ventilation rates when spaces are unoccupied, e.g., from 6 air changes per hour (ACH) minimum when occupied to 4 ACH when unoccupied. Significant energy savings are possible. To be extra safe, rates should only be reduced when spaces are both scheduled to be unoccupied and also indicated to be unoccupied by the occupancy sensor. *Figure 2* shows a hardwired connection to an optional auxiliary contact on the occupancy sensor provided for lighting control.

Modern "smart" soft-wired occupancy sensors do not have an option for auxiliary contacts; usually the most cost-effective way to interface with this sensor is using a BACnet connection to the lighting control system, with occupancy status failing to "occupied" should the network connection be lost. A relay could also be wired to a light fixture controlled by an occupancy sensor, but the lighting controls would need to be programmed to turn on the light when occupants are present; if programmed for auto-off and manual-on, someone entering the lab who does not switch on the lights would not be detected.

- Hoods have sash closers with an override-close contact from the BAS. Sash closers are an option that not long ago were not cost-effective. But the largest hood manufacturers now offer factory installed sash closers, which reduces first costs substantially. The motorized sash closers include occupant presence sensors that detect whether someone is standing in front of the hood. If not, after a time delay the sashes are automatically closed. Safety beams across the face of the hood prevent the sash from closing when there are obstacles in the opening (similar to a garage door closer). Sash closers improve energy savings through enhanced VAV use, enhance diversity factor to reduce lab exhaust system capacity and associated first costs and space requirements, and increase laboratory safety by ensuring hoods are closed when not in use.

The contact from the BAS shown in *Figure 2* is an option that forces the hood closed despite occupant presence during an emergency loss of supply air to the lab to reduce exhaust rates, so that lab negative pressure does not cause excessive exit door forces. This is an event often overlooked in lab designs: if the supply air to the lab fails, e.g., because a fire/smoke damper closes or the air handler fails or is shut off, while exhaust to the lab continues, the lab pressure can be so negative that occupants cannot open doors to exit. One solution is to reduce lab exhaust fan speed or open fan inlet bypass dampers, but that risks exposing occupants to fumes before they have a chance to exit. Another option is to install expensive and architecturally unattractive pressure relief dampers to the outdoors. But simply commanding the sash closed during this event is a better solution and another advantage of sash closers.

- Fume hood monitors are provided with the hood, not with lab air valves or by BAS contractors. This option allows the monitors to be the same for both CAV and VAV hoods, and first costs are reduced since they are factory installed with no field coordination or installation labor. This design is not possible with all air valve controls; some require use of their own hood monitor. Others highly recommend it since they offer additional alarms and features such as a convenient way to plug into the air valve controls for configuration. Having a separate fume hood monitor also can lead to a mismatch in airflow readings between the monitor and the air valve controller, which can lead to possibly false alarms; on the other hand, this could also be viewed as an advan-

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tage with one serving as a back-check to the accuracy of the other.

"Slow" Lab Control

"Slow" labs are those for which airflow rates required to meet cooling loads or minimum ventilation rates exceed hood exhaust rates. Hoods in "slow" labs (if there are any) may be CAV-type since no energy benefit exists to making them VAV; the same airflow rates are required whether the sash is open or closed.

Figure 3 shows "Slow" lab controls using BAS controls. Features of the design include:

- Standard VAV boxes and controllers are used. Because there are no VAV hoods, the need for fast-acting controls is eliminated. Therefore, to minimize first costs, standard VAV boxes and standard VAV box controllers may be used. The supply air VAV box typically will have a VAV box controller with integral velocity pressure sensor and integral damper actuator. The exhaust VAV box can be controlled by an auxiliary controller designed for dual duct VAV systems. For manufacturers that don't offer dual duct auxiliary controllers, a standard single-duct VAV box controller can be used with a hardwired connection from an analog output on the supply air controller to an analog input on the exhaust air controller to pass the exhaust tracking airflow setpoint between the two controllers. This setpoint could also be via the control network but, as noted above, hardwiring ensures no delays or disruptions due to network traffic.
- The hood exhaust air valve shown in *Figure 3* is the venturi type that is inherently pressure independent without a feedback control loop. These valves and their controllers do not generally have any damper position feedback to use with exhaust static pressure setpoint reset. Instead, a differential pressure (DP) sensor must be installed across the valve, and the exhaust static pressure setpoint is reset to maintain the DP across one air valve to be the minimum required for proper operation. The DP sensors are a factory installed option with some manufacturers.

- A separate controller is shown monitoring the fume hoods. These points may also be tied to the VAV box controller if there are sufficient spare points.
- Occupancy is monitored for off-hour ventilation rate reduction as discussed above for *Figure 2*.

Sequences of Operation

With dedicated lab controls eliminated, the burden of providing control logic and programming now falls onto the BAS designer and programmer. Detailed sequences of operation for a VAV lab with hot water reheat is shown in "Laboratory VAV Reheat Zone Sequence of Operation." These sequences apply to both "Fast" and "Slow" labs and have been successfully applied to several lab projects. The style is based on ASHRAE Research Project RP-1455[4] sequences, which are being adopted into ASHRAE Guideline 36P,[5] expected to be published later this year. References are also made to trim and respond control logic used in these two documents and explained in an earlier Engineer's Notebook column.[6]

Conclusions

First costs can be reduced and performance can be improved by using the BAS to provide all VAV laboratory control, eliminating the need for dedicated lab controls. One key recommendation is that each lab with VAV fume hoods have a single controller to ensure fast-acting yet stable performance. Detailed, proven control sequences are also another key element; the sequences provided here have been successfully used in several lab projects.

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5. ASHRAE Guideline 36P, *High Performance Sequences of Operation for HVAC Systems*.

6. Taylor, S. 2015. "Resetting Setpoints Using Trim and Respond Logic." *ASHRAE Journal* 57(11). ■
