Side Note This writer has a healthy skepticism for the conventional wisdom regarding laboratory airflow control systems. This wariness is based upon some considerable personal research, extensive testing, and then development and construction of mock-ups to prove alternate hypotheses. The results suggest that laboratory airflow systems design could benefit from the ventilation concepts initially developed by the "Old Saints" of the Atomic Energy era.

Contain yourself: Other Views

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How did the modern laboratory airflow control concepts develop and what lessons should we have learned from others before us along this way?

The laboratory airflow control system in most common use today is based on dilution ventilation. Was this always the case or did this evolve as a matter of design convenience? Why? If we continue with this concept, will it be:

> as a design tradition, ("We've always done it this way.")
>
> for convenience,
>
> on the basis of science,
>
> on the basis of voodoo, or
>
> on the basis of ignorance of anything better?

Joanna Turpin made the following statement. Was she correct?

> ***When it comes to making sure a fume hood system is safe, there are many factors that an engineer must take into consideration. However, the final goal is always containment - if the fumes aren't contained, the system isn't safe.***

The simple answer is **YES**, of course she's correct! The next question that needs to be asked is "How do we do this?" This one however needs a thoughtful answer.

In the past two decades, the concept of "laboratory safety", at least as far as exposure to fumes is concerned, has been largely limited to discussions about fume hoods and their operation. Research, experimentation, and mockup model evaluations during the same time have revealed that we should more rightly have been talking about the entire laboratory ventilation containment system.

Early on, we sought to evacuate air containing odiferous material from a work area because it "smelled bad". Later, especially in the 1940s, we sought to contain radioactive materials in a fume hood and exhaust the air inside it because it killed people right now. The biological mechanism was most often acute inhalation poisoning. In the early atomic energy era, the lab technician glowed in the dark and set off Geiger counters when he inhaled radio active materials. The poisoning was easy to detect because it was acute and fast acting and the Geiger counters could tell us when a user was exposed. All could predict the unfortunate lethal outcome for the victim.

When we transitioned into the chemical era in the 1950s, we encountered a new challenge: toxic chemicals that were not necessarily acute in their contamination or biological reaction. The late Dr. Norton Nelson, a biochemist who headed the Institute of Environmental Medicine at NY Univ. for many years, often stated, "The dose makes the poison." Toxic doses in the range of one part per million (ppm) require a different set of precautions and safeguards than do exposures based on 10,000 ppm. In addition, we shifted from being concerned only about acute exposure to trying to prevent chronic exposure to hazards and toxins on which we had no reliable historical data to measure their toxicity.

RESPONSIBLE CHARGE

Now, let us speak to the goal of "responsible charge" on the part of the engineering designer. This is the engineer whose professional seal on the drawings makes him responsible for the proper functioning of the design on the paper. This is an awesome responsibility, especially when one realizes how many integrated components the proper functioning of a lab depends upon. The engineering designer assembles a group of component parts which he feels will do the job. He assembles them into a theoretical ventilation system based upon the assumption that each component will act to accomplish its particular control task and that all the components, once integrated into a system will perform as designed. Last but not least, the designer assumes that his design will work to accomplish needed goals that he may or may not understand or that the contractor will "make it work" to protect the engineer from his mistakes and errors.

And, what about "design defects" associated with product liability where a claimant may seek to prove, especially as it relates to the design engineer's selection of laboratory air flow control systems, that: (1) there was a safer alternative design; and (2) the defect was a producing cause of the personal injury, property damage, or death for which the claimant seeks recovery? This should be troublesome to engineering designers, especially in light of the "safer alternative design" meaning another product's design, other than the one actually used, that in reasonable probability: (1) would have prevented or significantly reduced the risk of the claimant's personal injury, property damage, or death without substantially impairing the product's utility; and (2) was economically and technologically feasible at the time the product left the control of the manufacturer or seller by the application of existing or reasonably achievable scientific knowledge.

An analogy from another arena would be a NASA engineer designing a Mars rover who specifies tires for the vehicle that are smooth. His reasoning is that he was told that he needs maximum traction, so he wants the maximum square inches of tread to grip the surface. This is accomplished with a smooth tire surface, like drag racers have. What the astronauts find when they reach Mars is that the surface is like talcum powder, and the tires just spin in the dust. What they needed were knobby tires, with a tread that provides traction by biting into the dust of the surface. The conditions in which the design was placed were different from the conditions expected, and the design failed.

Back to earth and our laboratory design engineer. He has been told that 100 fpm face velocity will make hood safe. This is the conventional wisdom. This is the tradition. Since everyone does it, it is convenient to find components and calculation tables to accomplish it.

For example, the engineer needs to design a 40 hood lab. He does so, with enough exhaust power to maintain 100 fpm airflow for all hoods, all with sashes fully open, the worse case condition. He is told to keep costs down, therefore it is a simple system. The system is physically large and incurs enormous capital cost of supply and exhaust ductwork, air handlers, exhaust fans, chillers and boilers. Its size is large because it needs to be capable of exhausting and supplying air 24 hours a day, 7 days a week. The air thunders around in an attempt to satisfy "the solution to pollution is dilution goal".

But, what if this system can be sized based on satisfying actual usage and maintaining 100 fpm face velocity at all times actual usage is occurring? Accu*Aire Controls has a "shareware" computer program that can predict the maximum number of hoods with open sashes at any given time and air flow rates needed. For this example, it turns out to be **17 hoods at full sash opening and 23 closed**, and this is based on design consideration of a **probability of usage of 25% and a 5 times safety factor! And if automatic sash positioners are installed that normally open the sash to a half open position, the air normal flow consumption is again cut in half (17 at half opening vs. 17 at full opening)**. And, if you don't believe our measured probably numbers, let us show you how you can *measure* and obtain your own probably values. **And, while our 40 hood system has been grossly oversized from a design, safety and expansion basis, what we will find is that there are probably no more that 8 hoods open at any one time!**

Now, how do you get the sashes to be closed when not in use? Well, (1) get the tooth fairy to close them, (2) train the user to close them, (3) designate a person as the "Official Sash Closer", or (4) install an Automatic Sash Positioning System (ASPS™) on each hood. All are good ways but the ASPS is the only one that can guarantee sash closure when someone is not in front of the hood. And, by golly, this automatically opening of the sash to half position when the technician approaches the hood, with his hazardous fume-emitting project in his hands (hands free operation), and automatically closing the sash to minimum position just might save someone some grief should an experiment get out of hand and an explosion or flash fire occur (safest hood is one with a closed sash).

Finally, but certainly not least, is the safety of the technician. Wasn't this system put in place for the sole purpose of safeguarding the technicians, whose job entails putting hazardous substances in the fume hoods so that various reactions could occur? Now, when the exhaust air handler, sized for 40 open hoods, is operating and there are only 8 hoods open, is there considerably more than 100 fpm at each of the 8 hoods that are open? Better still, if our face velocity was way excessive of 100 fpm with the 8 hoods in use, doesn't this mean that the bad fumes are sucked out even better? Sounds good; this is a logical conclusion. But, it simply is not true. To the contrary, research - ours and others - has indicated that the presence of the technician in front of the hood will cause eddy currents and back flows, causing him to be exposed to the very hazards the entire system was designed to prevent. Worse, he may experience it as simply a bad smell, because the concentration will be low. But, since he does this every day at work, for years, he is encountering a chronic exposure situation, which may delay and thereby masking the source of its lethal consequences. Accu*Aire's offers the ASPS™ keeps all sashes on all hoods closed and coordinates the exhaust to assure 100 fpm at all sash positions of all open hoods, and best containment within the hood is achieved this way.

Lastly, I will only mention these additional variables, as this is not an in-depth treatise. The engineer designer will position the supply air ducts and diffusers in accordance with standard industry practice for an office, if he is not told otherwise. Accu*Aire Controls aids specifying engineer during the design process to help keep supply "outwash" or supply induced high turbulent air from occurring and negatively impacting hood containment. Accu*Aire Controls also aids specifying engineers in selecting and specifying fume hoods with aerodynamic and other components and features designed to minimize eddies and back flows. Accu*Aire Controls doesn't want poorly functioning or failed job either.

Wouldn’t it be better if we had a control system that, besides having fail-safe features, also had audible and visual alarms to signal the operator that something is wrong? Accu*Aire Controls does this as a normal and standard feature.

Wouldn’t it also be better if, when the hood exhaust flow decreased, like when a fan belt is slipping, the hood face velocity control system automatically closed the sash to the right height so the proper fume hood face velocity was maintained? The ASPS control system feature does this. In addition, should the fan belt break and not exhaust flow exist, the ASPS feature closes the sash completely...again for reasons of safety.

WHAT ARE WE TRYING TO DO?

In some laboratories, the assumptions that underlie a design can mean the difference between life and death. When the threat is acute, we will know quickly if the system is working properly. An example is Ethylene Oxide. Casualties will be an obvious indicator. When the threat is chronic, like Benzene, it may be years before we know. Now, let’s examine the assumptions and their impact.

First, the researcher is putting his life in the hands of a system that he makes certain assumptions about.

The lab tech using the lab assumes that the engineer designed a ventilation system that will properly contain the carcinogenic, radioactive, biological, or flammable fumes that the researcher is working with in the lab right now. The problem here is that the lab may have been designed for one type of operation, but as time has passed, other hazards are introduced.

The owner's project engineer or the project architect also assumes that the engineer knows what it takes in the way of systems engineering to do this. The design engineer assumes he knows all about the strengths and weaknesses of all laboratory air flow control systems on the market as well as all the other products he will specify. This of course involves all the components, including the hood, ducting, controls systems, and air handler. The engineer may or may not have this knowledge, and he may not have been given a sufficient budget, but normally will consider whatever he knows as sufficient to do the job. Besides, comfort conditioning is the only goal isn't it?

The Owner assumes that the contractor for the lab knows what it will cost to do this process properly, per plans and specs, and is fully committed to spending whatever it takes to accomplish construction completion and provide safety for the researcher. And the contractor chosen really wasn't the one with the low bid was he?

What happens if is in not a perfect world, and all these assumption are not correct?

Second involves designing an appropriate ventilation system for the containment of hazardous material served. And, while this seems like a simple concept, it involves understanding on the part of the engineer regarding the usage and the application for the science or functions that will occur in the space. Our Mars lander analogy illustrated how this is not necessarily the case. In the lab, uses change and the materials being worked with in fume hoods can become more concentrated and harmful over time. Maybe we should take the view that the design should be for maximum containment, regardless of hazardous properties, especially in university or other research laboratories. That is, maybe we need to maximize the laboratory air flow system and its components to protect the user to the greatest extent possible so, even when he screws up, the system will still safe guard and protect him. Maximum ventilation containment is Accu*Aire Control's goal with its engineered product systems design and involvement through start-up and commissioning. It has to work, doesn't it?

The third concern centers around a host of professional issues regarding the engineer:

knowing containment is the goal,

knowing which hardware components will contribute to that goal,

knowing how to assemble those components into a viable system,

assuring the installation is done properly, and certifying the completed installation will accomplish the design goal.

- The fourth concern centers around a host of professional issues regarding the researcher:

  knowing the hazards, chronic and acute, of the materials being handled;

  knowing to conduct experiments with these hazards only in the fume hood;

  knowing what contribution he has to make to his own safety; and

  knowing what contributory negligence is when he does not know about is own safety.

The fifth concern is operability and reliability. Operability deals with simplicity, maintainability, and accessibility, i.e., the KISS (Keep It Sufficiently Simple) concept. Reliable and sustainable ventilation system operations, like those intrinsic to Accu*Aire designs, include "fail safe" features. These provide visual and audible alarms when abnormal conditions are detected. It is for this reason that when the Accu*Aire Control's system was developed, the basis chosen was an analog 0-10 vdc electronic logic. Analog components have been around for a long time, are simple, and seldom fail. They are proven, reliable, and most important, can be checked with a voltmeter by anyone. Equally important, 0-10 vdc circuits interfaces to all BAS digital systems. Connecting to someone else's digital system for monitoring offers another level of safety monitoring while still allowing anyone with a voltmeter to easily check for proper operation at the local device. KISS. Besides, sometimes owners don't like it when their digital system fails and they have to sent everyone home; this hurts production.

Next, let's consider codes and standards. In addition to the previously mentioned considerations, we must always consider the requirements imposed by the government and our technical associations. Most of the time our intent in reviewing codes and standards is compliance with the standard. However, is simply complying with the "letter of the law" enough? Does evaluation of a design against such documents as 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories*, having a *Chemical Hygiene Plan* in place or satifying NFPA 45, *Standard on Fire Protection of Laboratories Using Chemicals* guarantee containment safety? What about ANSI/AIHA Z9.5-1992, *American National Standard for Laboratory Ventilation*; ASHRAE 110, *Method of Testing Performance of Laboratory Fume Hoods*; and the dictates of **Prudent Practice for Handling Chemicals in Laboratories**?

The codes and regulations, while well intended, are compromises made after years of negotiation. They do not respond quickly to change, especially change which all engineers and contractors have become comfortable with and which would cause them considerable trouble to implement, at least the first time. Aren't we all are resistant to change? But, maybe we really ought to re-consider the concepts each time we face a project, and the goal? CONTAINMENT.

Ok, what are the primary containment goals in laboratories where chemicals are used?

> **First, maximum containment of materials in the fume hood, under all operating conditions.**
>
> **Second, maximum containment of materials in the room that houses the fume hood, under all operating conditions.**
>
> **Finally, if possible, provide comfort conditions for users working in the rooms that houses the hoods**. But we really don't have to do this to protect the technician.

It thus must follow that these containment requirements, in the final analysis, must govern. And how do we do this?

> **Maintain fume hood face velocity constant at all openings regardless of static or dynamic hood sash position or airflow control system response dynamics**. This is a condition of use defined and proven during the Atomic energy era and validated and confirmed by several independent groups. Accu*Aire Control's does this.
>
> **Always return the hood sash to its minimum opening. Best containment occurs at minimum sash opening, regardless of the presence of a user in front of a hood**. Accu*Aire Control's systems does this.
>
> **Select hoods on the basis of their aerodynamic characteristics, including airfoils, perforated baffle sections, curved sidewall sections, full slot pickup across the back baffle section, etc. so that the hood aids in the containment process**. This aerodynamic consideration largely evolved from the early work done during the atomic energy era. And while Accu*Aire Controls does not do this for a designer, we can help. Of course this may mean hoods need to be selected as an engineering entity instead of a CSI Division 11600 architectural entity. Woops, another change for owners, architects, engineers and contractors: fume hoods selected on the basis of containment performance, construction, and features,

> rather than aesthetics and color?
>
> **Design the laboratory air supply system so the supply flow delivered into the laboratory flushes thermal and chemical emissions released in the laboratory toward the hoods**. Do this in a way that does not cause disruptive drafts in the workspace, especially in and around the hood face. Again Accu*Aire Controls can help; we maintain a full scale working model mock-up facilities where we try concepts and devices out. And, we still find that when we don't know, one good experiments provides considerably more useful information to us than a lot of opinions.

THE CAPACITY PROBLEM

The next "big picture" issue according to some is capacity. Well, how much capacity do you need? Since most users of labs really do not understand the containment and the owner's engineering rep also fails in this consideration, there is a tendency to want to influence design to replicate what they had before. Why, well simply because they are familiar with it. As an example, if they had a paper towel in the hood that wiggled when the hood operated, they assumed this was an indication that the hood was doing a good job, even if the face velocity was 200 fpm or more. Is this good? Does more air flow and higher face velocity result in safer labs, or is all the excess air "wasted" in producing fume hood face velocities greater than the 100 fpm desirable goal? This brings use back to the basic concept identified above. Is the message we ought to be getting across is that we: (1) need VAV systems for best containment and (2) we need to a way to close the sashes or keep them at minimum opening, something users will not do on their own? Don't we now have proven technology that can be used, based on being able automatically to close the hood sash when a user is not in front of a hood, with constant face velocity controls that can allow us "minimum but adequate" capacity design with proven results? Accu*Aire Controls thinks so and is willing to prove it to potential clients who have a genuine concern for ventilation containment safety.

Also with regards to capacity, what about those labs where ductwork was designed on a 100% capacity basis only to witness an additional few hoods added to the space? Is there any relief for this problem? Accu*Aire thinks so. If you have automatic sash positioning systems on all hoods controlled coupled with constant hood face velocity, when will the supply and exhaust system ever run at 100% capacity again? If you want to find out capacity and energy saving potential in your labs, use the LOADS simulation program with site specific weather data at **http://www.accuaire.com** or ask us to do it for you.[1,2]

Finally let us note that fume hoods exhaust huge amounts of air to the outside. Why? Is it because code requirements prohibit recirculating air from fume hoods back into the room or is it because of fear of a concentration build up? Regardless, all this air must be made up by the building central heating and air conditioning system. This means that the HVAC system in the area of the lab needs to be bigger, with more and larger ducting, just to replace the air being sucked out by the fume hoods. Accu*Aire controls automatically scale back the make up air to coordinate with the volume actually being exhausted from all the hoods (open and closed) at that moment.

NOW THE BIG ISSUE: CONTROLS

How do we control our laboratory air flow control system to make it do what we want it to do? What does all the mumbo jumbo mean? Open Loop vs. Closed Loop and System Pressure Independent Control vs Pressure dependent Control? Digital vs Analog? And what about speed of response?

Since the 1940’s engineers have struggled to produce economic fume hood controls and perhaps we best start with a definition.

> Definition: A closed loop control[3], or ***feedback*** control system is one that measures actual changes in the controlled variable and activates the control device to bring about a change. In this case we are talking about the fume hood exhaust valve controlling the fume hood exhaust flow. The corrective action continues until the variable is brought to a desired value within the design limitations of the controller. This system of transmitting the value of the controlled variable back to the controller is known as ***feedback***.

An ***open loop*** or ***feed forward*** control system does not have a direct link between the value of the controlled variable and the control device. ***Feed forward*** control systems anticipate, without measurement, how an external variable will affect the system.

Currently no laboratory airflow control system manufacturer has a closed loop system based on measured fume hood face velocity. Several individuals have been working on satisfying this goal and while some have succeeded technically, no means of measuring average face velocity across the face of fume hoods has been achieved that poses no threat to the laboratory technician. Inasmuch as personal safety is the driving force of the fume hood to begin with, research and development continues.

The next question is so, what concepts have we tried and what have we learned? Well, currently two basic approaches have been taken to producing a signal that can be used to control hood exhaust flow with the goal of controlling fume hood face velocity. One scheme is referred to as the "***through the [hood] wall***" design and the other is referred to as "***sash position sensing***" design.

With the "through the wall" [face velocity] design, a control signal is generated by a sensing device mounted in the hood side wall and is used as a transmitter to set hood exhaust flow rate. This design been tried several times, always with poor results, especially when only one sensor is used. As air flows over the sensor, a heated wire, convective cooling of the element takes place and a current or voltage signal is produced proportional to the cooling effect of the sensor. Under ideal conditions the convective cooling of the heated sensor can be scaled directly with the velocity of the air as it moves across the sensor. The problems with the heated elements in this application are numerous and well documented in the literature. They include:

> Sensor drift caused by dirt or other material building up on the heating element, affecting sensor sensitivity.
>
> Sensor signal to noise ratio. The electronic signal resulting from air flowing and convective cooling over a thermal sensor is "noisy" (it varies a lot) and any air turbulence on the cooling process is readily detectable. Attempts to gain sensitivity and faster response with these sensors is achieved only by driving the heating circuit at greater power, essentially making the circuit more sensitive to the cooling effect. This is not very energy efficient. At the same time, this produces more noise in the signal resulting from the turbulent flow across the heating element. This greater noise must be filtered to produce a stable control signal. Then it must be "averaged" to be of use in the fume hood exhaust control loop. This severe manipulation of the signal has been a factor contributing to the defeat of all electronic heated element control circuits associated with *"through the wall"* face velocity controls.
>
> A single sensor in the hood is susceptible to inaccurate extrapolation of the airflow value over the entire hood face. This has to do with secondary currents that exist when air flows into any rectangular opening. Smoke tracers can be used to indicate the existence of multiple counter rotating eddies that exist across the opening of a fume hood. **This is illustrated in Figure 1**. These eddies resemble an array of "mini-tornado" type secondary flows (cork screwing type eddies) that seem to form at the hood face and then move inward to the hood cavity. Like a tornado, they form a funnel, each along its individual centroidal axis, with the axis somewhat perpendicular to the plane of the hood sash opening. As the smoke tracers move into the hood cavity, it appears that the centroid axis of the swirl shifts in a somewhat randomly varying orbital mode around what appears to be swirls of little "mini-tornadoes" type eddies along the hood wall. The velocity signal measured from a "through the wall" sensor under the influence of a dominant swirl exhibits a somewhat sinusoidal variance with time, ranging from ±80% of mean value in some cases. These eddy currents and their impact on turbulence and hood face velocity were also studied some years ago in a fume hood where, the (fume hood) air velocity was measured at each of sixteen points in a hood face. What was found was that velocity in a well preforming hood was on the order of 100 fpm ±10%. In addition, it was observed that the fluctuations in normal hood face velocity could be explained by or associated with the movement of the secondary flow eddies in the hood face.

Figure 1
(red eddie currents along wall are strongest)

What does all this mean? This means that true uniform face velocity into a hood is not possible. Moreover, the problem appears to be greater with hoods in their full open position and with eddies more pronounced at higher flow and face velocities. In addition, the size and strength of the secondary flows seem always to diminish from the hood walls inward to the center of the hood sash opening. Is the problem new? No.

Seems Prandtl figured the eddy currents were caused by turbulence that occurs, producing secondary currents along the hood wall. In 1961, the experiments of Gessmer and Jones confirmed the Prandtl hypothesis regarding secondary flows. Additional support to Prandtl's hypothesis regarding secondary flows was presented by Einstein and Li.

The existence of these secondary flows, especially along the interior hood walls impacts the performance of a velocity or pressure sensor when mounted through the hood wall. Hunting of exhaust flow from the hood resulting from exhaust controller cycling sometimes occurs.

When a vertical rising sash hood is closed, the sash begins to act like an orifice and two things occur. First, with sash closure, the pressure within the hood chamber tends to becomes more uniform. The controller "sees" this and response improves. Secondly, as the sash closes the number of eddies that exist in the hood face is reduced.

Honeywell is credited with creation of the first through the wall fume hood face velocity control system design. This concept is reported and discussed at length in Homer Clay's *Controlling Fume Hood Exhaust in Atomic Energy Laboratories*, published in 1950 Attempts to use and develop this first prototype system were done in Hanford Nuclear Energy plant in Richland, Washington.

In 1980, Honeywell again attempted to introduce a *through the wall* hood velocity control system, however this time using the Honeywell VELOCITROL™ . Application of the VELOCITROL™ device, conceptually the same as that associated with heated element sensors, was improved somewhat by Honeywell's recognition of the "sidewall eddy problem". Honeywell used a "snout" extension that both lengthened the flow path through the hood side wall and, more importantly, displaced the end of the path away from the hood side wall. This is where the eddies are of highest strength (they diminish in strength from the side walls to the center of the hood because of viscous effects). Honeywell no longer markets this sensor for use in this application. This is moot testimony to the fact that the device did not work all that well.

In 1985, TSI introduced a heated element sensor similar both in principal of operation and concept to the Homer Clay era device. Because the device is impacted by the same physical factors as previous designs, it exhibits the same poor performance that ultimately defeated Honeywell’s initial effort.

Accu*Aire's 1985 patent applications specified the use of two or more heated elements, mounted on opposite side walls of the hood. Averaging these independent signals produced a single output to a controller. Moreover, Accu*Aire’s design showed that three sensors mounted this way (two on one side wall and the other on the opposite side wall) worked better than two sensors. With ever increasing numbers of sensors, the single averaged control signal produced better results. The logical extension of this concept is to remove one end from a fume hood and replace it with an array of independent velocity sensors. Unfortunately this is not practical from a commercial application standpoint. A more stable and repeatable signal for controlling hood face velocity can be generated by means of measuring hood sash opening. This uses a potentiometer to indicate measured hood sash opening. Knowing the size of the opening, exhaust flow can be adjusted to achieve the appropriate face velocity

The through the wall velocity sensing concept employed by TRIATEK, Norcross, Georgia, utilizes dual heat element sensors. It suffers not only from the through the wall design flaws just discussed, but also because of the "spring and cone" valve that they, Phoenix, and Air Precision Devices along with others use.

Ok, so there are some sensing problem to solve and some technical "hills to climb". And now what is the difference between system pressure dependent vs. system pressure independent and how does this impact our fume hood control goal.

The major negative contributing element impacting accuracy and precision of flow control with fume hood sash position has to do with the type valves employed in some systems, i.e. if the control concept includes pressure independent vs. pressure dependent valve operation. The **1992 ASHRAE** *SYSTEMS AND EQUIPMENT HANDBOOK*, Chapter 2, ALL-AIR SYSTEMS, page 2.10 speaks to the concern between system static pressure independent vs. dependent valve operation in variable air volume (VAV) systems to whit,

> "Pressure-independent volume regulator unit control the flow rate [through the valve] in response to... [a sensor's] ...call for ... [air flow]. The required flow rate is metered and maintained regardless of fluctuation of the VAV unit inlet or [outlet] system [duct pressure]..."
>
> Pressure-dependent devices control air valves control volume in response to a maximum volume unit.. [control sensor's call for control response]..., but the flow rate ... [being un-metered], varies with the inlet [or outlet] pressure variation [in the duct system ahead or behind the valve]. Generally airflow oscillates when [duct system static] pressure varies. These ... units do not regulate the flow rate but position the volume-regulating [damper or valve] in response to a ...[sensor's call for control response]..

So what is the major negative contributing factor impacting accuracy and precision of flow control with fume hood sash position and what does it have to do with the type of valves employed in systems. The problem with any design concept using static pressure dependent valves in variable air volume (VAV) systems is that you can not repeatably and predictably set the flow with damper position only. Pressure independent volume regulators or VAV units over come this problem by incorporating metering flow rate across the valve and positioning the valve to what ever position is required to produce a given flow rate in response to a sensor's "call". Simply stated the required flow rate is maintained regardless of the fluctuation of the inlet or outlet duct system pressures impose across the valve. In addition modern system static pressure independent valve can be factory and easily field adjusted to produce maximum or minimum airflow settings, i.e., "stops" and can operate with differential pressure across the valve as low as 0.2 in. W.C.

The ***spring and cone valve concept***, **illustrated in Figure 2**, integral to the Phoenix, Flow Safe, and TRIATEK systems all suffer from the fact that the valves are not system static pressure dependent. The TRIATEK system perhaps suffers more in performance because of the compounding effect that this system employs for indirectly sensing velocity across dual heated *through the wall* elements. If the signal from a transmitter to a control circuit is not correct, then use of a spring and cone type valve that is not system static pressure controlled can only make a lack of control problem only worste.

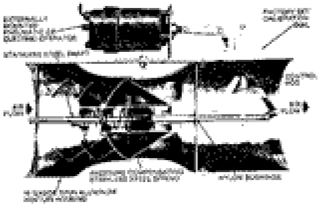

Figure 2

The big debate over what makes a fume hood safe is whether the control system produces a consistent fume hood face velocity, regardless of the hood sash opening. How ever since no laboratory air flow control system (LAFCS) actually measures the velocity of air entering a hood through the hood's sash opening, all systems must control by sensing something else to achieve this goal.

Flow regulation then, if not controlled by a "through the wall velocity sensing scheme" is normally controlled by sensing the opening of a hood's sash and control response is determined by:

> how accurate and precise the sash opening sensor is (i.e., consistently transmitting the same signal at the same sash position as the opening of the sash varies),
>
> how the controller or control loop receives this sash opening signal,
>
> how quickly the controller of control loop responds to a change in the sensor signal, and
>
> how consistently (accuracy) and time responsively the system produces the desired results in flow to achieve maintaining the same fume hood face velocity.

Experience has proven that a closed loop control incorporating system pressure independent valves is much better suited for this application than an open loop system and that a system static pressure control valve concept must be used to accomplish this. Otherwise the control loop positions the valve but lack flow feed back needed to be able to determine if the valve has been closed or opened enough.

This assumes of course a desire on the part of specifier to achieve desired control of hood exhaust flow and thus hood face velocity, to yield repeatability of flow needed to establish ±1% of required face velocity at the same sash position (static mode) and ±5% in a dynamic mode, regardless of duct system pressure. These are Accu*Aire Control's goals. And, these goals are not possible when system pressure dependent valve are used for fume hood face velocity control purposes.

Another argument associated with control loops has to do with digital versus analog controllers, especially electronic. The speed of response of both type control loops has largely been limited to the speed of the valve's pneumatic actuator. If a single closed loop electronic controller is used, the device performs internally at the speed of light. Digital controllers do not perform calculations at this speed, because the control circuit has been retarded. Many of the digital systems now on the market have been developed primarily for temperature response control. In most situations, this is very satisfactorily handled by a slow control loop, typically employing a delay of as much as two seconds. Experience has shown that the use of an analog electronic controller, one per each control loop, eliminates this concern and adds considerable reliability to overall system performance. Electronic analog closed loop controllers can also include proportional, integral and derivatives (PID) functions, provided on a cost effective and competitive basis, offering some additional system advantages. However, we have also found that the derivative part of the controller is not needed in these applications.

WHAT FACE VELOCITY?

The reason measured face velocity in the hood sash face is such an issue is because it is has been, and continues to be, the standard used in the U.S. to evaluate containment performance of a hood. In the early Atomic Energy Commission (AEC) days of draw through only laboratory air flow control systems, good ventilation containment was achieved with fume hoods. This was when the air flow into the hood was uniform across the hood sash opening and was not influenced by central conditioned air, which was not then available. If the velocity entering a fume hood was uniform across a hood's sash opening, low turbulence existed in the hood and best containment was achieved.

With the introduction of forced air systems in laboratories (push-pull), containment performance changed but the criteria used for measuring containment performance, face velocity, did not. Hence, the industry continued to use face velocity as an index for containment, although containment was not necessarily achieved in all forced air situations. Since few were willing to attempt testing to correlate escape of radioactive emissions with face velocity in push-pull laboratory air flow systems, no one stopped to question the results based only on face velocity.

Compounding this problem was, and it still is, the type of instrumentation used for measuring fume hood face velocity. In the early AEC era, swing vane velometers like that offered by Alnor or rotating velometers were the instruments of choice for air velocity measurements. The hot wire anemometer was later employed for this purpose. Anyone who has taken face velocity measurements with either of these recognizes that both are very sensitive to the turbulence in the air at the single point where the measurement is being taken. Consequently, a great deal of creative interpolation on the part of the user is often required to obtain a value. The impact on performance associated with push-pull air systems can also be demonstrated by comparing "As Used" (AU) results with "As Manufactured" (AM) results. AM figures are obtained with a fume hood tested in a large room having no supply air or supply system (no supply influences). AU figures come from the same hood tested in room situation where the supply system is typical for a lab installation. They are considerably different and do not vary predictably.

Many users agreed that a uniform 100 fpm face velocity across all hood sash openings is the optimal setting. Others disagreed. The correct answer however depends on what is being done in the hood, i.e., the chemical being used and its danger to the user. Since the "poison is in the dose and the chemical", a hood containing steam (H_2O) liberated at 4 liter per minute in a hood operating with a face velocity of 50 fpm might be OK. However, Ethylene Oxide (EtO) liberated at the same rate of 4 liters per minute offers a totally different containment requirement for the safety of the user.

Homer Clay offered insight as to why the majority of users have focused on a uniform 100 fpm face velocity across all hood sash openings as optimal. His explanation in 1950 had to do with what was observed to occur when Bunsen Burners were used in a fume hood and the hood was operated at 50 fpm face velocity setting. It was observed that thermal buoying, lifting the air into the top of the hood, was more significant than the containment velocity needed to eliminate fugitive emission escape. Users, after determining that 50 fpm was the lower limit and about 150 fpm was the upper limit (to keep eddies from forming in front of the user), appeared to have arrived at the consensus that 100 fpm was optimal, with this value offering the best margin of error from a statistical stand point. Another factor dictating 100 fpm as the optimal face velocity had to do with the instrumentation in use at that time and its ability to measure velocity with any level of confidence at 50 fpm.

Regardless of face velocity setting, history shows that the face velocity should remain constant even when the sash is being repositioned at the same value. The ability of a fume hood to contain material degrades if the face velocity drops below or goes above certain limits, even if temporaraly. A sudden high or low flow condition resulting either from the face velocity control circuit being too slow with time (predominantly with sash opening) or too fast (predominantly with sash closing) can allow fugitive emissions to occur. The control loops should be configured to be "fail safe" and should include indicators showing hood flow with hood sash position independent of the closed loop control circuit. There should be audible alarms when the flow exceeds certain limits (±5%) when the hood sash is repositioned, or a system flow upset when the hood sash is static (±2%).

In addition, enhanced hood safety features should include a feature that automatically repositions the hood sash downward with a loss of exhaust flow. In addition it should automatically close the hood sash and place the hood in a purge mode if a high temperature or concentration limit occurs, either within the hood or external to the hood.

WHAT ARE THE CONTROL GOALS?

If a control system doesn't measure and control the hood exhaust flow in response to a calculated or indirect measured face velocity, and velocity entering the hood through the sash opening is the basis for containment ventilation, a laboratory air flow control system will not work as intended. For those arguing in favor of open loop systems and faster reaction time in positioning a valve, a critical review of desired function is in order. Rapid repositioning of a valve in a non-system static pressure independent system does not equate to proper (set point) flow, proper face velocity, or containment ventilation within the hood at all operating conditions. Besides what control response time is needed, how is it defined (time lag between set point changed when flow change within prescribed limits is achieved), and how is it measured?

> Should it be 1, 2, 3 or 4 seconds?
>
> By what control standard and against what variables should it be measured?
>
> Do users, especially in labs where explosion or fire hazards exist, open and close hoods fast enough to need these response times?

If containment is the issue and flow across the sash opening of a hood is one of the means necessary to achieve this goal, users will usually choose a particular vendor's laboratory air flow control system based on its ability to achieve the desired control advantage. And if achieved, to reliably sustain needed level with minimum maintenance attention, but with user notification of alarm conditions when they occur. Experienced engineers have to know what is important to containment ventilation, how it differs from dilution ventilation, what the control system can do and what its limitation are with regard to meeting the control objective. In addition, most important, what features and how should they be incorporated in to a laboratory air flow control system to gain maximum containment, often in spite of the user.

LOW FLOW, ENERGY, AND CAPACITY CONSIDERATIONS: WHICH WAY TO GO?

Some suggest that fume hood users move away from measured hood face velocity as the means of judging containment performance, and switch to ***containment challenge*** testing as the required standard. A review of the fundamentals associated with use of these two methods however suggests that the methods are not in variance with each other. Fume hood safety revolves around containing material liberated or generated in a hood and conceptually centers on laminar iso-kinetic flow, i.e., uniform velocity of air through the opening in a hood sash to achieve this goal. If fume hood face velocity measurements are done with a pitot-static tube system using sixteen tubes mounted on an equi-area basis in the hood sash and the arithmetic mean value of 100 discreet face velocity measurements associated with each point are made complete with the standard deviation of the measurement about the mean (and index of turbulence at the point where the measurement is made), an excellent correlation between ***challenge containment*** level and face velocity exists. Moreover, this was the essential means of judging containment in the early AEC days when Geiger counters were used to detect radioactive emissions in early draw-through, or pull, systems. If a hood performed well, uniformity of face velocity with steady flow sufficient to guarantee containment of material in the hood existed. When the industry went to push/pull systems, accomplished with a subtle change from ventilation containment to dilution ventilation, mechanisms reflecting air flow patterns in the room and hood (how air enters the hood, how air is exhausted from the hood, and what the actual functions are inside the hood) became more significant as factors impacted and disrupted the containment goal. It is for this reason that measurement and control of the uniformity of face velocity at the same level, regardless of the hood sash opening,ensuring that the turbulence level is the same, regardless of room supply or hood aerodynamic and similar features, proves to be so significant.

Containment Challenge *is defined as a process where a high purity tracer gas is released inside the fume hood at a know and constant rate. The concentration of this tracer gas flowing from the hood counter to the air flow being drawn into the hood for containment purposes, is measured and used to quantify hood containment under a particular operating scenario. The current industry recognized procedure in use for accomplishing this and for metering and reporting results is the American Society of Heating, Refrigerating and Air-Conditioning Engineers' Method of Testing Performance of Laboratory Fume Hoods, ASHRAE Standard 110.*

It is understood that labs are terrific users of energy because maintaining constant face velocity regardless of sash position is the only significant way of guaranteeing containment. The difficulty with this economic reality has nothing to do with face velocity but rather has to do with being able to insure that the hood sash is routinely returned to its minimum level. Users generally leave the sash open, requiring the fume hood to operate at maximum air flow. An Automatic Sash Positioning System (ASPS™) is the only reliable way of concurrently guaranteeing containment and reduced flow at all sash openings. This means having controls that automatically open a sash to its half height position when a user is detected in front of the hood and automatically closing the sash when a user is not in front of the hood. This strategy is touted as the most effective way to provide maximum containment and at the same time save money.

In contrast, if the sash remains at the same setting and the face velocity and hood exhaust flow are reduced when the user walks away from the hood, i.e., the "unoccupied" situation, it is reasonable to question the gain. This concept, referred to as face velocity "zone presence sensing" dictates that all conditions have to be perfect if maximum containment is to be achieved when the hood face velocity is reset from 100 fpm to 60 fpm. Perfect conditions are not the normal situation and containment can therefore reasonably be expected to suffer. Those experienced with working laboratories understand that requiring the operator to keep the hood sash closed as much as possible, while simple enough in theory, it simply does not work. Operators resist performing this function even if done for their own safety. The ASPS™ is much more reliable, and can be configured to be fail safe. Moreover, where labs have a large number of hoods in them, maintaining face velocity constant with hood exhaust flow tracking supply flow eliminates certain kinds of cross drafts that occur from the dynamics of the room that could possibly pull hazardous or noxious fumes out of the fume hood and into the area that is occupied.

The use of ASPS™, constant face velocity control, and variable exhaust flow with supply tracking exhaust flow is the best response to customer requests for achieving maximum containment and low flow under all modes of operation. In addition, when a laboratory air flow system does not have enough capacity, yet a customer wants to add more hoods to a lab, ASPS™ provides an alternative to an expensive retrofit. Customers don’t have to lower the face velocity of fume hoods to free up capacity for other fume hoods that need to be used. If a lab is supply or exhaust deficient, a system can be converted to variable volume. And, the ASPS™ feature can be added to ensure that the hood sashes are kept closed when a user is not working in front of the hood. And, when ASPS is relied upon to keep hoods closed when no user is present, the supply and exhaust systems can be reduced in cost and size in new and retrofit situations. Tremendous energy savings, sometime as much as 80% and with simple energy payback within 12 to 24 months after installation is the primary reason that fume hoods equipped with the ASPS™ feature installed with lab VAV systems is catching on so well.

Now the key issue: installing a true constant fume hood face velocity control system with ASPS™ to achieve true containment ventilation, and then not using the containment system properly. The best system in the world won't work well if it's not used properly. A properly designed, configured, installed and calibrated fume hood with ASPS™ and constant face velocity at all sash settings will not produce the desired level of safety if operations are allowed on the benches that should only be allowed in the hood. Thus, in addition to designing a safe system, with proper control system features that work correctly and reliably, engineers must also take the time to educate the users. There needs to at least be a safety coordinator at the facility who understands containment ventilation in a hood, how the system should work, how it tells the user it is not working and what to do to correct it. In the end, we can not protect the individual who chooses to do work on a bench that ought best be done in the hood; not control system can stop him to insure his safety.

PEARLS OF WISDOM BASED ON HISTORICALLY SUPPORTED FACT

On constant vs. variable volume: Is constant volume safer than variable volume? No, quite to the contrary, this is demonstrated by historical fact. Weber proved it early on in the 1940s with his constant face velocity, variable capacity mechanical mechanism that was incorporated into the early AEC fume hood and became the standard for containment ventilation control. In addition, the Weber mechanism also incorporated a mechanical quick closure feature for use in the event of an upset in the hood. The best containment in a hood is always achieved with a hood operating at constant face velocity and the sash opening always minimized. Authorities generally recognize that if the closure orifice size is reduced, fugitive emission escape will always be reduced, with or without constant face velocity. However, with constant face velocity, as the hood exhaust flow rate is reduced, the fugitive emission escape is also reduced. Or more simply stated, if you do not want smoke coming from the room into the hall, close the door to the room. The same applies to fume hoods.

On pressurization: Experienced engineers know to use tracking systems, which is where the supply and the exhaust are synchronized so that they track with a fixed offset, exhaust flow being the greater. The use of pressure control systems, where the differential pressure is measured between the room and the corridor will not produce desired results. Laboratories are not just office spaces with research going on in them. They should be considered areas of high hazard, where flow rates need to be fixed and the direction of flow guaranteed so fugitive emissions from hood to room, and room to hallway can be eliminated and made fail safe.

On work practices. It's really the proper application of the containment ventilation concept to the laboratory that counts. Granted, it helps if the hoods have been designed on an aerodynamic basis and other features and the make-up air introduced into the room does not disrupt the flow and velocity of air drawn into the hood at the hood face. In all cases however, the hood is always a box with moveable window in it that is not capable of control of any variable. Control of air flow must be achieved by the control system, designed to do a specific task within acceptable time constraints.

On capacity: Making sure that there is enough fan capacity for the supply and exhaust air systems is both a design and construction concern. Poor construction with improper calibration of a control system can defeat the control intent of any design engineer. Likewise, the best craftsmen, employed by the best contractors can not make an improperly designed system work. ***Diversities*** can now be measured in buildings by type of operation and used in system designs with a reasonable safety factor applied to insure that minimum, but necessary, capacities exist in all control situations. There are no excuses now for system failures. ***Diversity*** *as used herein is defined to mean the fraction of fume exhaust flows as a percent of total net exhaust flow (i.e. maximum system design capability, with all devices on and operating at 100% of device capacity), assuming each device is operating at full flow capacity. It is usually expressed as a decimal fraction or percentage of total net flow.*

On writing a specification and being in charge: Understanding how ventilation systems work and how they should be operating, if installed correctly by the builder, is key to the system's success. Specifications should dictate performance and should clearly describe how individual components are brought together to produce a working system that operates as intended. There are differences in system and how they perform; our patent laws see to this. And, contractors should not have to approach a job with the specifications simply requiring the purchase of a "bucket of parts" that the contractor has to assemble and try to make work. What this really means is that the specifying engineer must really understand the control systems he specifies. He must either have the ability himself to specify components to accomplish the job, or have a subcontractor in whom he has confidence, through recommendation or experience, that he can do the job. And the engineer and the controls contractor best ought to go to the job and be involved in the start-up if all really wants to keep the product liability claimant away.

Finally the choice of a particular hood should also be take into consideration. The hood ought to be purchased on the same performance basis as engineered grilles and diffusers and not on an aesthetic basis that centers around the color scheme of a room. Colors do not guarantee containment ventilation performance or influence how air flows into a space into a hood and is exhausted to the atmosphere. Aerodynamic design of the hood components near the sash opening can have a large impact on the eddies which form, or don't form, inside the hood. In addition, the location of the hood and the location and type of air diffuser will have a large impact on how the hood will function. Also, while aesthetics are a consideration, containment ventilation is the ultimate goal.

In the final analysis, a laboratory is like a symphony. If beautiful music is to be produced, all the elements of the symphony must work together. It is likewise the same for laboratory air flow control systems.

END NOTES:

Rock, James C.and Anderson, Swiki A., *Design Principle for Self-Amortizing Variable Air Volume Integrated Lab Ventilation and Fume Hood Systems*, APPL. OCCUP. ENVIRON. HYG., October, 1996.

Rock, James C. and Anderson, Swiki A., *Benefits of Designing for Ventilation Diversity in a Large Industrial Research Laboratory -- A Case Study*, with James C. Rock, APPL. OCCUP. ENVIRON.HYG., October, 1996

The 1991 *ASHRAE APPLICATIONS HANDBOOK*, Chapter 41, AUTOMATIC CONTROL, page 41.1

Prandtl, L.; *Turbulent Flow*; National advisory Committee for Aeronautics, Technical Memorandum No. 435, Washington, D.C., October, 1927.

Gessner, F.B. and Jones, J.B.; *A Preliminary Study of Turbulence Characteristics of Flow Along a Corner*, Trans. ASME, Paper No. 61-HYD-4, 1961.

Einstein, H.A. and Li, Huon; *Secondary Currents in Straight Channels*, **Trans. American Geophysical Union**, Vol. 39, December, 1958, pp. 1085-1088.

Clay, Homer B.; *Controlling Fume Hood Exhaust in Atomic Energy Laboratories*, HEATING, PIPING & AIR CONDITIONING, June 1950, pages 77 - 83.

The *1992 ASHRAE SYSTEMS AND EQUIPMENT HANDBOOK*, Chapter 2, ALL-AIR SYSTEMS, page 2.10

Anderson, Swiki A., *Control Techniques for Zone Pressurization*, ASHRAE Transaction NT-87-04-01, June 1987.