THE EVOLUTION OF THE MODERN LABORATORY AIR FLOW CONTROL CONCEPTS AND THEDEVELOPMENT AND LESSONS WE SHOULD HAVE LEARNED FROM OTHERS WHO HAVE GONE BEFORE US

INTRODUCTION

At least four different lab technicians/chemists at different chemical plants along the Gulf Coast have had their lives and careers altered interrupted by health problems in the past year caused by laboratory exposure to hazardous substances in the laboratory at work.

LeAnn Miller has been on extended medical leave since August 1999 and is now on an intravenous drip 20 hours each day for nourishment and faces major surgery on her intestines. Her doctors tell her she will never work again. Her job and her company insurance can be terminated any month. Reportedly, the company never filed a workman's compensation claim and recovery under this procedure may not be available to her.

Tina Kreig had to resign from the company where she had worked for three years because her physicians told her she could no longer work in a lab. She is concerned because her hair is falling out. A toxicologist will start doing liver and kidney biopsies shortly. This dismal prospect for the future is compounded by the fact that she now has to pay for her medical payments as her termination left her without coverage by medical insurance.

Michelle Piggott's career as a lab technician ended when she became pregnant for the second time and her doctor detected a problem with her condition and the baby she was carrying. Then he learned she worked in a chemical plant lab. She developed symptoms of what was initially diagnosed as lupus. Her oldest son received treatment for "failure to thrive" when he turned 5, because he had the same weight and height normally expected of a 3 year old. She worked in an environmental lab and used methylene chloride daily in a phenol extraction process. The poorly ventilated lab had a fume hood with 10-12 air changes per hour, when it was on. However, the extraction process was not performed in the hood. She complained daily to her supervisor and his boss without avail until she was fired because she finally refused to continue to work in the lab.

The air conditioning in all these labs worked properly. None of these individuals ever complained about the temperature or the humidity where they worked. Why did they get sick? What is the common thread that forced them to leave good paying job for their health? In most cases these individuals worked in labs that had good air change rates, running 10-12 air changes per hour or better. Why were they not protected?

Most often lab workers and their managers assume a lab is a safe environment if the air conditioning and humidity are properly controlled. They fail to realize that safety in a laboratory is solely concerned with the ventilation system containing hazardous emissions in the fume hood and exhausting it from the lab. The hood has a secondary goal of collecting the residual fumes from other sources within the lab and sucking them outside, through the hood. What the Heating, Ventilation, and Air Conditioning (HVAC) system does to keep lab personnel comfortable, though related, is a separate and distinct function. Most air conditioning systems rely heavily on reuse and recycling of air inside the building because of economic concerns, but not in labs.

Laboratory workers, their managers and safety professionals must realize that the dose makes the poison. Daily-prolonged exposure to low-level chronic toxins or suspected carcinogens, even in trace amounts, can cause irreversible harm to laboratory workers. Often the health of the supervisor is at risk at the same level as the technician working in the lab[1]. Addressing and fixing ventilation-related work-place problems is in the best interest of any employer, both from an economic and employee health viewpoint.

What you think is working may not be working. How do you know it is or is not? Does your lab's HVAC system comply with the codes while the safety issues that prodded creation of the codes remain overlooked? How can labs be made to work correctly? There is a solution to this laboratory containment ventilation problem and it lies in our past.

LABORATORY AIR FLOW CONTROL SYSTEMS (LAFCS): THE FIRST STEP IN ACHIEVING THE BEST

CONTAINMENT VENTILATION

Thomas Edison was probably one of the first to be concerned with laboratory ventilation. He worked in a primitive laboratory with heated rubber compounds that gave off noxious fumes and odors. Figure 1[2] This situation quickly led Edison to use the fireplace chimney to exhaust fumes from his laboratory. The thermal buoyancy of the heated gases assured the fumes and odors exited out of the room through the chimney, at least in the winter. Unfortunately, the natural draft exhaust system failed to work in the summer and Edison's solution to the problem was to built a shelf outside the window. He placed the experiment on the shelf, and closed the vertical rising sash in the window to keep the smell out of the room. This appears to have been the first use of a vertical rising sash for fume control.

Figure 1 - Thomas Edison: The Wizard of Menlo

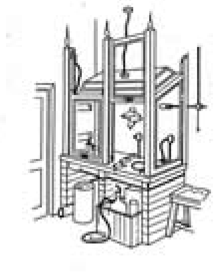

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Figure 2 illustrates what was called a "fume cupboard" like those in use in 1923 at the University of Leeds in England. It incorporated vertical rising sashes arranged like parallel windows[3].

With the United States' entry into World War II and the beginning of the Atomic Era (1942-1965), necessity prompted great strides in laboratory ventilation system development. Tragically, lives were lost in laboratories at that time because of increased exposure to highly toxic chemicals and radioactive materials. While these losses were catastrophic, there were, on the other hand, significant safety, ventilation and fume hood design lessons learned during this period.

John Weber, Jr., working at the Ames Laboratory in Ames, IA, developed the first concept of a constant face velocity, variable exhaust flow fume hood control. This design was applied to a vertical rising sash hood[4] served by a dedicated hood exhaust fan. The system, illustrated in Figure 3, consisted of a rack and gear arrangement that used a cam to open a damper mounted in the hood exhaust duct. The effectiveness of the system to achieve constant face velocity with various sash openings depended on how well the cam was designed and built. This mechanical approach was used to achieve the optimum relationship between sash movement and damper position for each individual hood. This, in turn, produced a specific hood exhaust flow at a particular open sash position. The concept did eventually become a standard feature employed on many fume hoods at that time in atomic laboratories, especially where ventilation containment within the hood was critical.

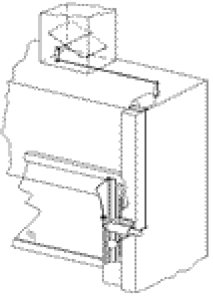


Figure 3 - Weber's Automatic Fume Hood Flow Control, damper and hood circa 1943

Clearly, Weber's system worked and worked well. The ability of his mechanical system and the direct linkage between the sash of the hood and the damper in the hood exhaust and the linear cam profile established depended upon the skill level of the person who made the cam for each hood. Weber's invention disclosure reveals that electric and pneumatic devices were considered and rejected because of lack of speed and fail-safe considerations.

In addition, he stated:

"The problem was developing a positive controlled action through the face opening of the hood without causing turbulence or other action sufficient to cause eddy currents, back drafts, etc. of such a nature as to provoke any danger from toxic or radioactive materials with regard to the operator of the hood."

NOTE: The eddy currents referred to are those occurring along the sidewalls of the hood at hood entrance. Flow is induced by momentum gradients existing in the plane of the hood opening. Wakes are caused by the presence of the operator in front of the hood. In addition, wakes are sometimes present because the stream line path of make up air into the hood is not perpendicular to the hood face at a distance far enough removed from the hood opening. Remember this was a draw through flow arrangement. It had no flow distortion caused by make up air being forced into the laboratory room.

"It was felt that in order to safe guard against possible back drafts, eddy currents, etc., it was necessary to develop a control mechanism to satisfy the following conditions:
1. The establishment of constant [uniform] velocity through the face of the hood.
2. The development of a true automatic control to ensure the above constant velocity at any position of the door of the hood.

NOTE: Weber and the early scientists recognized that best containment in a hood was always achieved with minimum hood sash opening and with face velocity across the available sash opening constant and uniform across the sash opening, a truism that exists still today.

3. To develop in addition the possibility of manual control to provide increased velocity when needed.
4. The establishment of an emergency release of the door of the hood by the operator with the additional provision that the damper must be re-set to automatic position before the operation can resume operations of the hood."

Weber was also concerned with being able to close the sash rapidly for maximum containment when an emergency arose and his system included a locking device that allowed sash movement in one direction only, with operator reset before normal operation could be restored. Inclusion of these features indicates that Weber recognized the vertical rising sash type fume hoods contained best when the hood sash is closed or at minimum opening, and with constant face velocity control employed.

As stated in his invention's disclosure, Weber's system was applicable only to non-air conditioned laboratories with the sole purpose of containment of materials in a hood. However, this was not the only aspect of his laboratory airflow system that aided containment and some discussion of these features and attributes merit greater consideration. Clearly, the goal was to contain materials in the hood via constant air velocity through the available sash opening and keeping the sash at minimum opening at all times aided this containment ventilation goal.

To truly appreciate what the early AEC laboratory scientists and designers developed, one must consider Weber's idea and the means of gaining containment ventilation they achieved. Interestingly enough, the early AEC labs did not have air conditioning and were selected and located where it was not needed. Energy conservation and operating costs were not factors. Consider Los Alamos, NM at an elevation of 7410'. The anticipated high temperature for a summer day in this location is 57°F[5]. This implies that comfort conditioning of the air entering a lab building by cooling the air is not needed. The ventilation system applied in these labs utilizing Weber concept were "draw-through" only. The scientists working in these labs were concerned only with containing life-threatening materials in the hood so they did not breathe it or become exposed to it. By utilizing a "draw through" variable air volume hood exhaust flow scheme, room supply was slave to, and automatically varied as a function of the hood exhaust and sash position. Supply airflow was exhaust flow induced in response to the hood exhaust flow rate. Both flow rates (supply and exhaust) were dependent upon hood sash position. Moreover, the AEC typical laboratory at this time consisted of a single-story building with construction configuration illustrated in Figure 4.

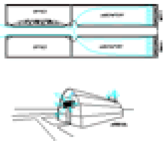


Figure 4 - Artist Concept of Early AEC Laboratory Building Arrangement

The typical laboratory buildings had a central personnel/service corridor along its major axis with laboratories off both sides of the corridors, as shown. Fume hoods were most likely installed along the exterior walls of each laboratory module. A single dedicated, roof-mounted, belt-driven exhaust fan powered each hood exhaust. With this configuration, make up air for the hood was drawn from the outside of the building, through a unit heater mounted above one of the hallway exterior doors, down the hallway, through a louver in the laboratory door. The resistance to airflow into the lab was only slightly greater with the door closed than with it open. This arrangement immediately suggests that the following relative pressure relationships: most negative in the cavity of the hood (---), less negative in the room (--), even less negative in the hall way (-), and neutral outside the building: containment path was directional always toward the hood and was sustained as long as the hood exhaust fans operated. If an upset occurred and materials were released outside the hood, the safe course of action was to exit the room and thus the building. Several other subtle but significant features were lessons that can be learned from these AEC laboratories:

> First, if hood containment were not being achieved, a Geiger counter placed to a user's chest would quickly indicate failure of the hood and failure of the airflow system to contain materials in the hood. Containment testing was the norm and this type of testing differed little from the gas challenge testing concept now being used; it was better than the gas challenge test however.
>
> Second, it was recognized that if the face velocities became too high or were not right, "…turbulence or other air action sufficient to cause eddy currents, back drafts, etc. of such a nature as to provoke any danger from toxic or radioactive materials as regards to the operator…"[6] would occur. Too high a face velocity, or too low a face velocity, was obviously known to be a bad trait.
>
> Third, the safest way to use the hood was recognized to be with the hood sash closed. The appropriate emergency response by the operator to an unplanned event was to close the hood, exit the room against the inflow of clean make up air into the room, and Weber included a feature that addressed this with his system.
>
> Fourth, as air entered the room through the door, it swept the room and all materials liberated or generated in the room toward the hood. Disruptive eddy currents associated with forced supply flow were absent. The air entering the hood was drawn into the hood in a somewhat uniform (iso-kinetic) flow.
>
> Hood face velocity, given this type of room, hood arrangement, and instrumentation used to take face velocity readings produced an excellent index concerning the effectiveness of hood containments. This was partially because the supply airflow into the room did not induce eddy and other problem in the hood's face; these negative effects "die" out before room make-up air was drawn into the hood. If the velocity reading were uniform across a hood's face opening and consistently repeatable with hood sash opening, the flow control system was doing its job and excellent containment resulted. It is also interesting to note that hood face velocities were often reported in units of "lfpm" which stands for linear feet per minute, implying that the measured value stood for the velocity component normal to the face of the hood sash opening, a significant but often overlooked consideration.

> Finally, because the flow control means (controlled only by the exhaust flow from the hood) were stable and produced repeatable results, the engineers and scientists were free to focus on modifying and eliminating those aspects of fume hoods that were detrimental to containment ventilation and disruptive to capture and containment within the hood, to include hood entrance geometry, baffling and other associated features.

The Weber concept was basic, simple and easy to maintain. The air train excluding the hoods was well thought out and performed better than almost any other systems installed since that time with regard to containment, ventilation and performance. Because precise and accurate control of air flow with sash position was achieved and was no longer a complicating factor in the air flow train systems approach, it was possible to differentiate the cause and effect changes and improvements with fume hoods.

Accu*Aire Controls, Inc. has now developed and markets an analog electronic (0-10vdc) closed loop control system. It meters and controls hood exhaust from the individual fume hood with hood sash position, electronically sums net hood and room exhaust flow. Using this net exhaust signal it makes the supply air flow track the exhaust flow either with a fixed off set or in isolated single room labs, equal to net exhaust flow. By using analog electronic controls, system response times are generally less than one second with flow repeatability of less than one percent (1%) of set point. This closed loop flow tracking concept allows almost perfect but improved replication of the dynamic control response that Weber's system concept was able to achieve.

AERODYNAMIC IMPROVEMENT TO THE FUME HOOD: THE SECOND STEP IN ACHIEVING BEST CONTAINMENT VENTILATION

Having achieved a means of flow control for laboratories that was stable and produced the same flows and face velocities with hood sash opening and satisfied the room to hall pressure differential relation and the other system aspects needed and expects, it appears that the early laboratory scientists and engineers then began to focus on ways to improve the fume hood. Examination of available literature, especially drawings, suggests that the early fume hood effort probably centered on construction of fume hoods that were shop built by cabinet makers, probably constructed from plywood or Masonite, with almost all utilizing a vertical rising sash. Apparently as the trial and error effort evolved, improvements were made on a stepwise incremental basis, correcting problems found and tuning the design as it progresses, almost always with focus on improvement of the aerodynamic aspect of fume hoods to aid and improve containment.

Figure 5[7] illustrates several progressions in fume hood development. Figure 5a indicates a plan view of the hood and what happened to the fumes or fugitive materials when thin fume hood walls were used, probably constructed from single sheets of plywood. In this situation the air entering the hood with its poor inlet conditions (sharp edges), caused the materials to be pulled forward and form eddy currents behind the sharp edges. Figure 5b illustrates the solution that a cabinetmaker would devise to improve the situation, i.e., strips of wood nailed or otherwise fastened to the normally flat sheets forming the hood walls. This however caused the same problems, especially with the center post and Figure 5c illustrates a simple "fix" via use of faring applied to the post much like "wheel-pants" applied to a small aircraft wheels to reduce drag. Figure 5d illustrates a "first" fix for the problems identified with the eddy formation associated with Figure 5a. The different iterations associated with Figure 5e reflect treatments applied to the hood side inlet walls, all concerned with sidewall airfoil improvement. While the 45º-beveled inlet was an improvement over that associated with the inlet condition shown in Figure 5b or Figure 5d>, the radius entrance and external shaped entrance elements reportedly represented a quantum leap forward with hood containment because of minimization of back flow from the hood cavity to the face of the hood. Use of the radius entrance and externally shape entrances posed a challenge however with the early AEC efforts when one considers that achieving these shapes resulted because of the skills of craftsmen; imagine how difficult this must have been to accomplish, especially if the entrance sections were hand fabricated from 10 gauge stainless steel sheet stock.

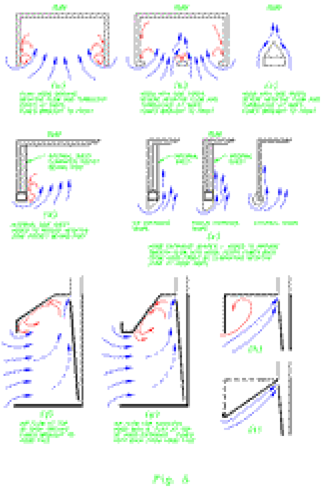


Fig. 5

And in each case incremental improvement was easy to detect and quantify with a Geiger counter, all the while with the hood exhaust flow essentially remaining the same because of Weber's mechanism.

Figure 5f and Figure 5g illustrate the flow pattern looking into the side of the hood. It is interesting to note the use of the partially sloped cabinet top illustrated in Figures 5f and 5g. Both indicate a reverse flow condition that existed with these hoods. This condition is even greater with hood having square tops as illustrated in Figure 5h and has to do with the downward vertical projection from the top of the entrance of the hood. Figure 5g reflects a partial improvement to elimination of the top reverse flow eddy that did little more than displace the downward circulation interior to the fume hood away from the user in front of the hood by use of the 6" flat at the top of the hood; this displaced the effect inward into the hood. Further improvement could have resulted from a streamline top entrance configuration in conjunction with the use of the Coanda effect (having to do with how a jet of air will be drawn to and will attach a cling to a surface) and its utilization in airplane wings that makes the air seek to attach to a solid surface. This is illustrated Figure 5i.

Figure 6a, b, and c[8] illustrates hood exhaust connections that focused on plenum type improvements and the effects that a slot in the back of the fume hood would have produced had it been easy to construct in the AEC era. Figure 7d illustrates a prototype fume hood that employed this type of arrangement; it represents the ultimate in exhaust duct connection schemes with regards to promotion of uniformity of velocity across the hood's face.

Figure 7a, the Vickery hood[9], illustrates a shingle type back baffle in combination with a full slot exhaust pickup connection. This combination represents a great improvement over the performance associated with the hood arrangements shown in Figure 6a or 6b. Figure 7b, the Lacey hood[10], illustrates an improved draw through hood eliminating system in combination with an improved full top slot, full width wrap around a perforated plate as a replacement of the back baffle. The idea for use of a perforated plate replacing the baffle come from an AEC baffle replacement with a air filter that was designed to trap low level radio active particles in the hood before it entered the exhaust system. This is illustrated in Figure 7c. In the case where the filter replaced the back baffle, the resistance of the full width filter, with flow though it into a chamber exhausted by a full width slot, promoted uniform velocity across both the filter bed and across the hood sash opening representing stream line flow to face of the filter media. This resulted with few eddy currents being created in the fume hood cavity. The fume hood arrangement shown in Figure 7b capitalizes on these two features and makes use of a "wrap around" full width top and back perforated plate as a replacement for the conventional back baffle. As illustrated, it also utilizes a full width slot across the upper rear of the hood to create the desired plenum effect needed to promote uniform flow across the non-uniform arrangement of hole in the perforated full width "wrap around' baffle replacement plate. With this arrangement the only eddy that would be expected to form in a fume hood would be that associated with Figure 7c, caused again by extension of the hood box to create a square top and promoted by cutting off the wrap around baffle to install the light in the top of the hood cavity.

Figures Figure 7a and 7b also illustrate a sash cap, that when used, eliminates any shear air flow that would be possible because of air flow entering the cavity of the hood behind the sash though the top of the hood. Air flowing down the back of the sash would normally attach to the back of the sash and would be at 90° to the air entering the hood normal to the face opening. This is illustrated in Figure 8a. Installation of a sash cap also results in all air entering the hood though the hood face, which also aids containment improvement.

Figure 8b illustrates the use of a foil over the opening of the safety shelf, a part of the hood base. The safety shelf was a simple addition on top of the hood base that would contain spilled material in that hood. Employing a foil atop the safety shelf to direct the air to sweep across the top of the hood for pick up and exhaust from the fume hood was apparently first used in the late 1940s and was highly touted as a significant improvement feature[11]. Figure 8c illustrates a slight but effective improvement associated with the use of foiled edges that was incorporated into both the Vickery[12] and Lacey[13] hoods. In the case illustrated with Figure 8c, note that the leading edge of the safety ledge has been rounded to match the geometry of the foil and the inward side of the safety ledge has also been shaped to promote better airflow at this point. Also accomplished but not illustrated is the rounding of the safety ledge along the sides of the hood and especially at the bottom of the "wrap around" perforated plate as it extends and terminates along the edge of the hood interior base.

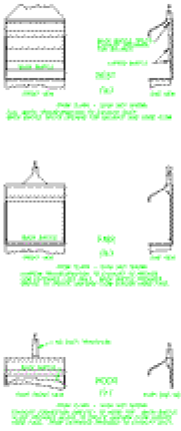


Fig. 6 - Hood Exhaust Connections

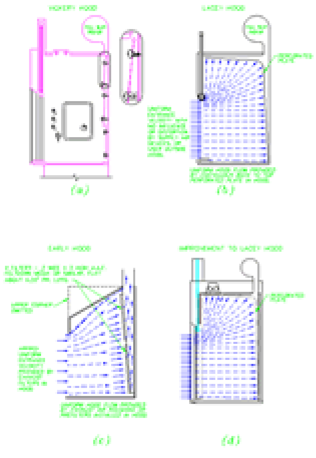


Fig. 7

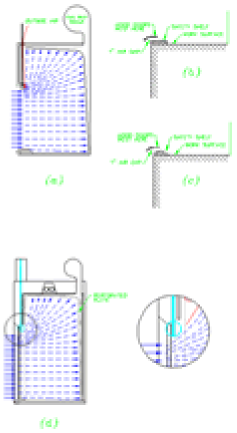


Fig. 8

Figure 8d, which represents the ultimate hood configuration as an improvement to the Lacey hood[14], also illustrates a two-inch diameter round attachment to the bottom of the hood sash. It represents what we anticipate to be the final step in developing the all-rounded entrance section with elements needed to promote optimum airflow across the entrance of the fume hood sash opening into the cavity of hood.

Figure 9a, illustrates a horizontal vortex that sometimes exists in fume hoods with both horizontal and rising sash hoods that incorporates a 45° upper baffle. Figure 9b and 9c illustrates how a vortex can form with the 45º upper back baffle, if it does form, decays in a vertical rising sash hood when sash opening occurs with reduced flow. Measuring the strength of the vortex as it decays and shifts position, and especially attempting to sense the vortex strength as a control-sensing means with its very low signal to strength, is not a viable means of measuring and controlling hood airflow. The vortex, when it exists, exists because of the dead space in the upper left hand side of the fume hood with formation created by the viscosity and shear flow of the airstream as it enters the slot above the upper edge of the upper 45º baffle. Figure 9d and 9e indicate how one manufacturer[15] purports to use the vortex to control containment within the hood. With this "Air Sentry" low-flow energy savings fume hood, supposedly the internal vortex is maintained by automatically adjusting the 45º back baffle. Besides obstructing the cavity of the hood with mechanical elements needed to lower the 45º upper baffle at the inboard edge, the control scheme lacks simplicity, and maintainability and sustainability of operation is questionable. And while some positive tracer gas challenge test results have been reported, at least one user has removed an installed system because of lack of containment and reliable operation[16]. If a properly designed perforated wrap-around plate were used in lieu of the back baffle, the vortex would not form and the advantages of a draw through system seem to still out weight those systems that incorporate mechanical "monkey motion" elements into them.

Figure 10a,b, and c[17] indicate various updraft hood arrangements tried in the early 1950s when attempts were being made to introduce air conditioning into the laboratories being built away form Los Alamos and Oak Ridge. While Figure 10a illustrates the Weber concept for control of hood exhaust flow with hood sash opening the referenced publication cataloged accuracy of the CONTROLLED FACE VELOCITIES published at 100 ± 20 fpm. Figure 10b in the original publication indicated PROPORTIONAL BYPASS LINK OPERATED with accuracy of 100 ± 200 fpm and Figure 10c indicates PROPORTIONAL BYPASS FACE OPENING accuracy at 100 ± 200 fpm. Clearly the by-type hood arrangements used, with a goal directed at attaining constant volumetric flow but constant inferential fume hood face velocity, did not produce desired results. It is also important to note what was published in the same source regarding the magnitude of face velocity as follows[18]:

> *"There are many variation of hood design devised to meet the criteria of reasonable face velocities, and selection of the proper design must evaluate consideration of required face velocities and economics. It is fairly well established that face velocities in excess of 200 fpm cannot be tolerated in this type of hood [radioactive] operation and there are far more instances where velocities in the order of 100 fpm are far more desirable"*

This is a restraint condition not satisfactory with the proportional bypass link operated or proportional bypass face opening type hoods. Moreover, the mechanical concepts employed in Figure 10b and 10c also failed to produce desired constant inferential results, especially in those situation where the proportional bypass opening is not of the same size at the sash opening and a grill covers the top opening, contributing resistance to flow but done for aesthetic consider. Figure 10c, 10d, and 10f[19] indicate various down draft arrangements tried, also utilizing vertical rising sash hoods. The down draft arrangements also failed to produce the desired results and only the design associated with Figure 10c survived the atomic era, even though containment and face velocity performance were defective when evaluated on the basis of measured hood face velocity or radioactive material containment determined by use of a Geiger Counter. The literature does suggest that hoods with greater than the nominal 32" depth, yields better containment performance with increasing depth, especially if the emitting source is placed in the back of the hood instead of at the hood sash opening. The notion that containment is enhanced with greater displacement of the emitting source into the hood has also been validated by Fuller and Etchells[20].

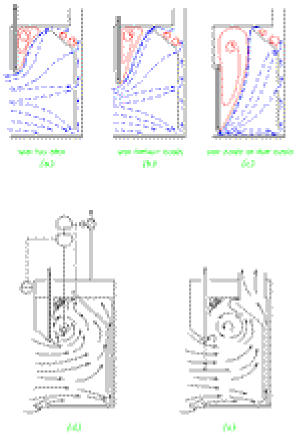


Fig. 9

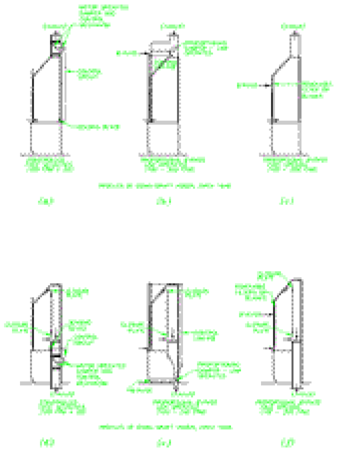


Fig. 10

Figure 11a and 11b indicates the HOPEC hood design[21] and represents a variation of the AEC era Figure 10c design. The HOPEC concept is that since a sash is rarely fully open, it makes no sense to establish a total exhaust requirement for the fully open sash position. The hood is converted to a bypass type vertical rising or horizontal sliding sash face configuration (with one panel always open). Sash locks are installed to require the operator to deliberately open the hood beyond the half height position. The hood exhausts and room supply flows are manually balanced to achieve a constant volume flow balance at the 50% hood sash opening and beyond that neither point inferential face velocity nor containment is qualified. This results in a guaranteed variation in fume hood face velocity and hence poor containment ventilation in both the hood often compounded by interfering room supply air delivery problems.

Figure 12a and 12b illustrates a hood arrangement introduced and reported by John Turner, Engineering Department, Oak Ridge National Laboratory (ORNL) in the early 1950s[22]. These were directed at exploring a number of special features associated with hoods, all considered as various means of reducing the consumption of conditioned air in ORNL labs, i.e., "saving energy". He stated:

"Recent fume hood improvements which facilitate laboratory air conditioning and make for a safe and usable hood comprise: 1) Constant rate of room exhaust and uniform hood face velocity for any door position by use of a bypass damper.
2) Reduction of hood face area open at any one time by replacing the conventional vertical sashes with horizontal sliding doors.
3) A safe 50 fpm laminar flow face velocity made possible by:
a) Elimination of side entrance corners and center posts.
b) Addition of contoured entrance shapes.
c) Addition of a 'safety shelf.'"

Turner suggested replacing vertical rising sashes with horizontal sliding sashes. Also, he promoted the use of a mechanical damper that worked off of the imbalance between external and internal hood pressures. This was based on the familiar principle of the heating stove automatic draft check damper. Aside from these modifications, the fume hood hardware scheme Turner suggested was a dilution based (bypass) constant volume and provided no real advancement in the hood aspect of containment ventilation. He attempted to use a mechanical spring-loaded damper commonly found in the residential furnaces at that time. Unfortunately, like hoods control schemes that incorporate both mechanical linkages[23], [24] and spring control devices subsequent to Turner's efforts, they have failed to perform properly when new and have become more problematic with use, because of the inability of technicians to maintain these linkage/spring based systems especially with corrosion, dirt or other foreign matter build up that restricts motion. One current example of this is the "linear spring and cone" valve with its attendant hysteresis problems that cannot be overcome[25 26 27]. The literature does not reflect utilization of Turner's hood concept beyond an experimental effort and, aside from some application knowledge gained, the hood and various forms of it seem to have lacked employment in any lab beyond an initial research effort. Turner's paper did present a summary of findings about the use of outside air make up hoods and he suggested reasons why ORNL dropped further attempts at refining and improving the outside makeup scheme on ORNL hoods. His findings only tend to add credibility to those published earlier, in that air flow delivered at the hood face, especially through an outside air bonnet delivering air parallel to and downward at the hood sash caused disruptive shear flow and excessive turbulence that often cause fugitive emission outflow from the hood cavity. This problem is often compounded and aggregated with air flow down the inside of the hood sash when a sash cap is not present, thus eliminating this air flow path. Delivery of outside air within the hood cavity has been found even more disruptive and has been eliminated by adherence to **NFPA 45-1996, Standard on Fire Protection for Laboratories Using Chemicals,** per section 6-8.6 Auxiliary Air, which states: *For auxiliary air fume hoods, auxiliary air shall be introduced exterior to the hood face in such a manner that the airflow does not compromise the protection provided by the hood and so that an imbalance of auxiliary air to exhaust air will not pressurize the hood interior.*

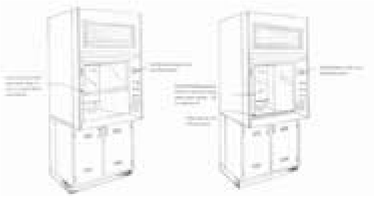
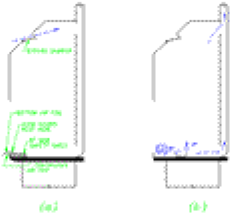


Figure 11 - HOPEC hood design



FROM TURNER

Fig. 12

In the last several years some attention and research has been done to isolate and try to find various improvements that focus only on the fume hood as a containment device. Accu*Aire Controls, though not a manufacturer of fume hoods, has supported research work and testing of fume hoods incorporating only vertical rising sash hoods in the last several years. Early on it was determined that use of a vertical rising sash hood in a "draw though" configuration in conjunction with variable hood exhaust flow from a fume hood controlled by hood sash position consistently yielded better containment result than various types of bypass type hoods used in constant volume laboratory air flow situations. Moreover, the draw through configurations lacking mechanical linkages or other "monkey motion" features has consistently proven easy to maintain with sustained operation. Accu*Aire's goal**28**, similar to the approach of others**29**, started out being one of finding suitable ways for field modification and especially of rebuilding existing hoods "in-place" to improve containment. The approach initially centered on the premise that all fume hoods were fundamentally a box with a front casing applied to them and significant containment improvement could be realized with a goal of changing some parts of a hood "in place" done at considerably less cost than total hood replacement. This was first directed at conversion of horizontal sliding sash or combination sash hoods to a vertical rising sash configuration. Horizontal sliding sash hoods, because of relative sharp edges associated with sashes and because of a lack of a suitable means of measuring hood sash opening for hood exhaust control purposes, were earlier, after testing, eliminated from consideration for safety considerations. Another contributing, but minor factor, was that horizontally sliding sash hoods were also found unpopular with users relative to vertical rising sash hoods. Use of any form of outside make up air was also eliminated from consideration because flow control, obstruction of user movement at the hood face, lack of containment performance, maintenance, operation and first cost considerations.

Accu*Aire's fume hood improvement focus has centered mainly on features and modifications that aerodynamically enhance the streamline flow of air into and through the hood in a ways to eliminate eddy currents and other disturbances that cause or aid in fugitive emission outflow under test and "normal use" considerations. This type research has been lacking for some time with the major manufacturer of fume hoods with modifications copied by differing manufacturers, often absent any improvements resulting from testing, and with sales aimed only at appeasing the often misguided whims of an owner when first price alone was not the determining purchase factor. The two significant fume hood containment improvement efforts partially supported by Accu*Aire were, first the development of the Vickery hood**30** and later the modification to this same hood with results obtained through features incorporated in the Lacey hood**31** discussed earlier. Testing is now underway with a modified and improved Lacey-type hood (see Figure 7g) to establish the optimal hole spacing in a perforated plate that will allow extension of "in-place" replacement of conventional hood types employing back baffle. The perforated plate approach for use as a back hood baffle is easy to install in field situations and offers several performance and user advantages, especially relative to uniformity of capture velocity across variable sash openings and hood exhaust air system maintenance. Other hood manufacturers incorporating use of perforated plates in fume hoods are Baker Company with their ChemGARD and ChemGARD-RI fume hood, ThermoQuest/Forma Scientific biological safety cabinets and LABCONCO invarious-type hoods. While the use of perforated plates was probably considered by Weber and others in the early AEC efforts of the 1940s, having to make such plates, especially as a part of a trial and error effort, especially with the use of a drill to form each hole, was omitted for obvious reasons.

One other effort directed at hood improvement warrants mentioning, that being done at the Lawrence

Berkeley National Laboratory, funded by the federal government. This "draw through" low flow hood concept focuses on the use of room air introduced at the base and top of the hood sash opening (via three small fans) to aerodynamically enhance streamline flow into the hood along the bottom boundary of the sash opening and the around the sash. By reducing resistance to flow along these boundaries with air streams forced into the hood cavity, it is possible with this scheme to aid and enhance the induction of room air into the hood through the available sash opening at a reduce volume and velocity without a lack of containment. The primary goal of this hood design is to be able to reduce the air volume drawn from the room needed for hood containment and thus hood exhaust. This is accomplished by the motive power of the three fans imparting kinetic energy to increase air velocity along the top and bottom boundary of the hood sash opening for capture containment. And while this has been done primarily for energy conservation purposes, good containment at select sash openings has also been achieved. The difficulty with this particular systems approach is that the hood flow is a constant volume and as the sash is closed, to a sash height of 10" or less (and especially with sash height openings of 6" or less) the average velocity of the air entering the hood through the core of the sash opening begins to exceed 100 lfpm and containment degrades more and more as the sash is closed. While this approach was considered at one time by Accu*Aire, it was not used because this type of hood requires more system elements to deliver room air needed to produce the desired velocity effects needed at the hood face. And with more elements more maintenance opportunities are presented (violates the KISS principle). In addition, Accu*Aire has found that lower room air flow consumption is possible with containment equal to or superior to that associated with the Berkeley Lab High-Performance Fume Hood. The Berkeley hood, illustrated in Figure 13, is a nominal four-foot wide hood, draws a constant volume 385 cfm of room air through and is discharged from the hood. In contrast, a nominal four-foot wide hood subject to variable air volume flow with sash opening (constant inferential face velocity) requires only 200 cfm room air exhaust for containment at sash closure (with this minimum amount being drawn from the hood through the lower foiled opening). If the hood operates at the sash closed position 5% of the time, an active use normally found in research labs, this means that for 456 minutes (100.0 - 0.05 x 8 hrs x 60 min/hr) during a normal eight-hour workday the hood is closed and an air consumption of 185 cfm (385-200) is saved. This means that with an operational costs of $8/cfm per year for conditioning outside air, a saving of $1,480 per year can be realized if the hood is subject to "active use" of 5% of the time during the normal work day and during active use,[32 33 34 35] corresponding to the 385 cfm hood exhaust at the half height position, and at containment levels equal or exceeding those reported for the Berkeley hood regardless of sash position. Because variable air volume hood operation should not be used in all hood applications (for example perchloric acid service requiring use of a wash down system) some form of low flow constant volume fume hood having excellent containment capabilities is needed and the Berkley hood may prove to satisfy this need with continued improvement. With regards to fume hoods, it is obvious that the initial choice of type of fume hood was the vertical rising type used in conjunction with a draw through flow control means initially developed by Weber. This type hood, especially with enhancements made after Weber's flow control system was employed, unquestionably offered the best containment. As the need developed to build laboratories in locations where cooling and dehumidifying of the air ("conditioned air" labs[36]) was dictated because of human comfort conditions, lacking suitable electro-mechanical control hardware and concepts[37 38], the use of constant volume air flow systems incorporating bypass type fume hoods, done for achieving building air balance, evolved. And obviously, though well intended, there were attempts to incorporate a variable air volume hoods with a constant supply air system with predictable and disastrous containment results. Unfortunately, with this evolution, use of constant volume bypass hoods resulted in greater opportunities for fugitive emission releases. This was largely because of sharp orifice type edges associated with sash openings, especially with horizontal or combination sash type hoods, and the inability of the laboratory air flow system to maintain precise and accurate[39] inferential face velocity or flow as a function of hood sash position. Other limitation were also recognized as follows in the conference proceeding of the 1950 **Laboratory Design for Handling Radioactive Materials:**[40]

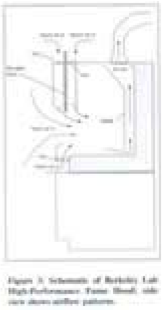


Figure 14 - Schematic of Berkeley Hood

Constant or Variable Air Quantity

In establishment of the building air balance it is obvious that the air-conditioning requirements and hood demand must be satisfied by the supply-air quantity. The question of whether the system should be of the straight through constant volume or variable volume type must be resolved on the basis of consideration involving the economics of controls and variable air.

Owing to the usual combination of space in type of building it has frequently appeared too economical to design on the basis of a straight through constant volume system. It must be remembered that this system is limited with respect to its capability as to the number of hoods. The number of hoods cannot be increased beyond the known constant volume provided.

A variable air system, of course, can be utilized to expand the hood capacities, and the desirability of this type system should be evaluated on any building since it expands the hood capabilities quite considerably and provides excellent hood operation…

USING A SASH POSITIONER SYSTEM: THE THIRD STEP IN ACHIEVING BEST CONTAINMENT VENTILATION

Weber recognized that best containment in a fume hood was achieved with minimum sash opening when he developed the emergency quick close feature incorporated as a part of his system. His concern was a sudden release in the hood and the need for some means for quick sash closure for maximum containment purposes. This consideration obviously came from an understanding associated with fugitive migration often observed when a smoke grenade is set off in a room and the smoke starts migrating toward the open door while the observer is standing outside the room observing the smoke. If one does not want outflow from the room through the doorway where the observer is viewing the smoke migration, the observer simply has to close the door to ensure containment in the room. It is also interesting to note that the exhaust fans used as a part of Weber's system were never turned off.

While a hood may be in continuous use with an experiment ongoing within it at all times, most would agree that maximum safe hood operations will always occur when a hood's sash is closed or at a minimum opening while the user is working in front of it. This is especially true if the exhaust system remains operational. In the vast majority of situations, laboratory technicians simply do not work in front of fume hoods all day long. They set experiments up and check them periodically while they go about doing other tasks in the laboratory. The conclusion concerning hood sash closure when an operator is not present in front of a hood is not new and was first espoused by H.W. Alyea, Chief Field Engineer, Johnson Service Co. (now Johnson Controls, Inc.) in 1951 when he stated[41]:

"The amount of air introduced into the laboratory is only that required to maintain desired face velocity through the hood doors. Since the hood doors are kept closed as much as possible for reasons of safety, this results in a considerable savings in the amount of air supplied [for hood make up exhaust], with proportional reduction in cooling demand, and considerable filter life."

Alyea's comments must be interpreted in light of the 1940s Atomic Energy era laboratories he referred to, i.e., those where the flow of air was used only as a means of containing fugitive material in a fume hood. It was obvious from the reference cited that Alyea was both familiar with Weber concept and mechanism; understood it, and endorsed how it worked and what it accomplished. What this suggests is that a hood's sash(es) should only be open or partially open when an operator is standing in front of the hood to accommodate operator manipulated activities within the hood. When an operator has a hood open and is manipulating something within the hood this will be defined as "active [hood] use." At all other times, there should be no reason for the hood sashes to remain open, hence the term "active use" and its application to fume hoods. This is particularly important when they function in a variable air volume system where exhaust flow is reset by hood sash opening, and is of special concern to cost-conscious laboratory owners and operators. And it is unfortunate that some hood users fail to recognize that the hood sashes do not act as valves, throttling hood exhaust as the sash opening is reduced, and that under no circumstances should an exhaust fan switch be installed on a fume hood if containment is a consideration. Being able to turn an exhaust fan on or off most often leads a user to assume he is protected when the fan is off, regardless of if chemicals are stored in a fume hood or building re-entry of fugitive emissions through an off hood occur because of back flow through the hood exhaust duct system.

The Accu*Aire sPs™ (Sash Positioner System), when installed in combination and control interlocked with the Accu*Aire analog closed loop flow control system, is also configured to allow immediate sash closure via an emergency manual push button tripped by the operator as he exits the room or is automatically tripped by a high-temperature sensor - in case of a fire - installed in the hood. In either situation, the hood exhaust is placed in a high-flow purge to ensure maximum containment with a fire, spill or other upset, always directed at maximum protection of the user by containing the incident within the fume hood. This is especially important in a fire situation when the sash(es) should be closed (without the operator having to approach the hood to accomplish this goal) with the flow of air into a fume hood accelerating to a maximum speed to contain flames within the hood as the sash automatically closes. This action would protect equipment in the laboratory, potentially sacrificing only the metal ductwork serving the hood while concurrently allowing rapid egress of technicians from the space and signaling other buildings to hurriedly exit the building for personal protection until a trained emergency response team can arrive on the scene and assess and respond to the incident.

The Accu*Aire system overcomes all problems associated with automatic sash positioner requirements due to creation of a Sash Safety Assistant (sSa™). The sSa is more cost effective than automatic systems because the sSa promotes hood sash/user interface, lowering installation and operating costs, and alerts the user to close the sash when not operating in front of the hood. This alert, either through an audible alarm or a lighted warning, eventually conditions the user to close the hood sash when not in use, allowing maximum hood containment.

CONSTANT UNIFORM FACE VELOCITY WITH SASH OPENING: THE FOURTH STEP IN ACHIEVING BEST CONTAINMENT VENTILATION

Homer Clay[42] was the first to define the reasons for use of 100 lfpm in hood applications. His reasoning for use at 100 lfpm was significant for sustained optimum hood containment, especially at full hood sash opening. Also significant was the understanding amongst the early scientists that flow of air must enter the hood with vector velocity perpendicular to the hood sash opening, at the same vector velocity uniformly distributed across the hood sash opening.

Some have suggested that face velocity measurements are not good criteria for judging the performance of a fume hood. In some rare instances this may be correct. However, a blanket condemnation of this method is not justified. Condemnation of the method and results obtained must be reviewed relative to how the measurements are taken and the context which they are applied.

In the early AEC era laboratories where Weber's mechanism was applied and the air flow system was draw through only with motive power supplied by the exhaust fans, face velocity measurement - when taken by someone knowledgeable concerning air flow problems in laboratories - gave excellent predictive results concerning containment capability of the variable air volume systems. From the prospective of the then fume hood users who could validate their face velocity reading with a Geiger Counter, and with their physical well being depending on face velocity measurements, they had to be accurate, precise and repeatable as a means of insuring correct air system performance. It is suspected that few safety professionals were willing to use radioactive tracers as a means of validating proper hood containment performance.

In a conference held in November 1951, several problems associated with air supply and exhaust in newly air-conditioned laboratories handling radioactive materials were identified and discussed. Many of the same concerns remain relevant and are critical to the safe operation of fume hoods today. They are partially repeated from *Proceedings, Laboratory Design for Handling Radioactive Material* as follows:

> **Safety**
> **Safety requirements also must be established during the early phase of design, and consideration must be given to operating conditions desired in case of disaster...**
>
> **Draft-free Requirements**
> **A considerable number of laboratories are being designed to provide draft free conditions in order to eliminate unnecessary movement of particulate matter throughout the room by air currents...**
>
> **Hoods**
> **Without question, hoods create most of the problems affecting the design of air-handling systems, and for this reason the need for hoods, their design, and the manner in which they are controlled are of vital importance in the design of a laboratory to handle radioactive material.**
>
> **Controlled Face Velocity**
> **With respect to the design of hoods, it is axiomatic that the hood face velocities must be controlled within reasonable limits on hoods handling radioactive materials in order to reduce the disturbances of lightweight material (being handled in the hood) by high velocity air. Control of the face velocities can be accomplished by designs meeting either**

> **of the following two basic concepts: proportional bypass (constant volume) and controlled face velocity (variable volume).**
>
> **There are many variations of hood design devised to meet the criteria of reasonable face velocities, and selection of a proper hood must evaluate considerations of face velocity and economics. It is fairly well established that face velocities in excess of 200 fpm cannot be tolerated in this type of hood operation, and there are many instances where velocities in the order of 100 fpm are far more desirable.**
>
> **Air Conditioned Hoods Undesirable**
> **Owing to the advantage gained through the reduction of supply-air quantities, considerable effort has been made to develop so called 'air-conditioned hoods.' These hoods are designed on the principle that "make-up" supply air for the hood is delivered at the hood. In some instances the air is delivered at the lip of the hood, in some at the top of the hood, and in still others directly into the hood itself. Most of the tests made with hoods of this design have disclosed that in some instances there is a counter flow of air at the hood openings, and, since this is wholly undesirable in a hood handling radioactive materials, hoods of this design are not considered practicable.**
>
> **Airflow Pattern**
> **Many laboratories are currently being designed on the basis that maintenance of a continuous pattern of the airflow from all the 'clean' areas into the hoods located in the laboratory space, is essential. Naturally the hoods are being designed to provide this airflow pattern.**
>
> **Controlled Face Velocity**
> **In a large complex laboratory, the economic studies should be sufficiently complete to disclose fully the benefits to be derived, if any, from the installation of controlled-face-velocity hoods.**
>
> **If controlled-face-velocity hoods can be justified economically, there is little question that the following advantages make them the most desirable type of hood: controlled face velocities in the range of 100 ±20 fpm, increased number of hoods per module, and reduced air distribution systems."**

In the early days, the fume hood sash opening, initially at full open position, was grid into at least nine (9) equi-area segments with face velocity measurements taken in the center of each equi-area segment. Instrumentation used was appropriate to the task and probably consisted of a special probe connected to a swing vane-type anemometer calibrated each time of use against quality reference standard with accuracy and precision of at least ten times greater than that of the meter being calibrated. Damping of the velocity signal within the meter was also of consideration. Use of such meters allowed meaningful and repeatable test data to be acquired. If the velocity at any one point was not within 20% of the desire set point of 100 lfpm (probably the RMS uncertainty of the meter used to take the measurements), the hood exhaust flow was increased until the minimum face velocity at any one of the equi-area points was 80 lfpm. Commissioning efforts at the time also included taking face velocity measurements at various incremental hood sash openings from full opening to partial closure, a very time-consuming effort.

The early commissioning effort is markedly different and produced much better performance and results than are now produced with face velocity measurements taken with a hotwire anemometer when the indicating needle is swinging wildly and the device user "visually" averages the indications may not yield the best data. Hence it is important to consider the accuracy and precision of the instrument, where and how the signal is read, the type of fume hoods and air flow control system in use before interpretation and judgment of the usefulness of the information it provides. However, the results are not necessarily meaningless even with data taken with a wildly swinging indicator needle.

To illustrate the utility of face velocity measurements in a fume hood, consider the array of individual Pitot-static tubes is installed in a fume hood face as is illustrated in Photo 2[43][44][45][46]. With this arrangement the velocity pressure signals from each Pitot-static tube is sequentially multiplexed and sampled with the same high-quality differential pressure transducer with air velocities calculated to produce significant measurement results. These results can be displayed and recorded with a computer, as illustrated in Photo 3, and be used to benefit fume hood containment ventilation and especially problem identification and correction.

Photo 2 - Pitot-Sstatic Ttube Array for Fume Hood Face Velocity Sampling

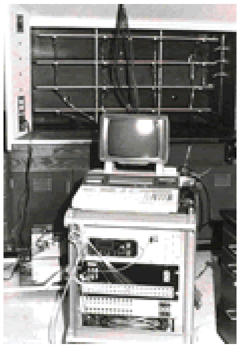


Photo 3 - Computer Driven Pitot-Static Fume Hood Face Velocity Sampling Scheme

When face velocity and containment challenge (ASHRAE 110 Test procedure[47]) data is taken currently with such a system, there is an excellent correlation between containment results and face velocity measurements results. In this situation, the average velocity sensed at each of sixteen probes was multiplexed back to and conditioned via computer. Associated with the velocity measurement at each point is the standard deviation of the 100 velocity pressure samples taken at that point. The standard deviations reflect the turbulence of the air in the vicinity of the probe. This information can be used to identify and isolate disturbance factors. Trace gas performance testing cannot yield information such as this but provides only "pass-fail" information. No assistance in isolating problems with flow into the hood or the disturbances that cause it result from the tracer gas challenge method. Figure 13 illustrates data taken with such a pitot-static face velocity measurement system.

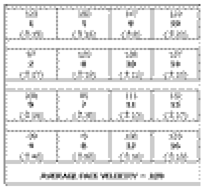


Figure 13 - Typical Computer Output Record for Pitot-Static Fume Hood Face Velocity Sampling Scheme

In this situation, the velocity pressure signals sensed at each of sixteen probes were multiplexed back to common extremely high quality differential pressure transducer with velocity pressure signals converted to velocities for each measurement via computer. Associated with these velocity measurements at each point, the computer system calculated the standard deviation of the each of the 100 velocity values at that point. The standard deviations reflect the turbulence of the air in the vicinity of the probe. Under ideal conditions the face velocity measurements would tend to range from 90 ± 7 fpm to 105 ± 7 at any of the 16 equi-area points and would consistently average 101± 7 when considered for all 16 points in the hood face opening. The turbulence information, i.e., that indicated with the ± value, can be used to identify and isolate disturbance factors such as that indicated by all points in the above example with the mean values for points 4 and 8 indicating other problems. Trace gas performance testing cannot yield information such as this, but provides only "pass-fail" information. Absence the availability of such data, no assistance in isolating problems with the LAFCS can be revealed. However, if the values were all nominally 100± 7 at each sampling point, there is good correlation between the results provided by the trace gas performance method (ASHRAE 110 Test procedure) and the average mean and turbulence velocity measurements in fume hood set up and test situations.

While some suggest that "average face velocity measurements" are not a good criteria for judging the performance of a fume hood[48], a blanket condemnation of this method is not completely justified. Granted, face velocity measurements taken with a hotwire anemometer when the indicating needle is swinging wildly and the device user "visually" averages the indications may not be the best data, but it is not necessarily meaningless. It is important to consider the accuracy and precision of the instrument, where and how the signal is read, and the usefulness of the information it provides. However even with these faults, sometimes even poor face velocity data taken with a hotwire anemometer can provide guidance to a knowledgeable safety professional concerning hood performance. Figure 14 illustrates such a situation where poor quality data was taken and recorded. Review of the data and knowledge of what chemicals were used in these fume hoods indicates that the problem in this particular situation is not what the readings indicate, but rather the lack of meaningful activity by those responsible to address and correct the ventilation containment problem identified. The same concerns associated with accuracy and precision hold true for rotating vane anemometers.

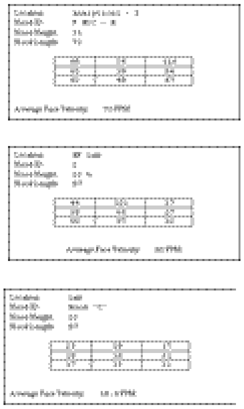


Figure 14 - An Example Of Face Three Velocity Measurements indicating Poor Fume Hood Containment Performance (Chemical Plant, Upper Gulf Coast)

Finally a significant problem exists today with the use of face velocity and LAFCS. Although commonly incorporated into system design, no LAFCS supplier can sense face velocity in an operating hood with currently available technology. If the average velocity cannot be sensed in an operating fume hood, how can fume hood face velocity be controlled? It is for this reason NFPA 45 dictates that hood flow, which is measurable, be indicated as a means of indicating hood performance. What LAFCS suppliers sense and what they control with their products is illustrated and discussed in "Changes to National Fire Protection Codes for May 2000" at **www.saai-svc.com/engineer/html/NFPA45.htm**. Safety and containment ventilation implied by some LAFCS suppliers lead the user to assume he is protected while in fact the hood face velocity reading may be false.

ROOM AIR SUPPLY FOR CONTAINMENT ENHANCEMENT WITHOUT DISTURBING THE HOOD FLOW AT THE SASH OPENING: THE FIFTH STEP IN ACHIEVING BEST CONTAINMENT VENTILATION

In the early atomic energy era no conditioned forced supply system existed and air motive power was supplied by exhaust fans only, and hallways and rooms acted some what like wind tunnels with air at low velocity always sweeping the hallway and room capturing and containing the materials as it moved toward the fume hood sash opening. Disruptive supply air being forced into the room and being discharged, especially in the front of the fume hood sash opening, was lacking. And also lacking was the high level of turbulence complete with eddy currents contained within the air as it moved toward the hood that is normally associated with forced supply systems. And while it has been demonstrated that the ideal fume hood would consist of a low velocity wind tunnel about 8' wide, 8' high and about 32' long, with a back constructed of perforated metal plate making full use of fully developed stream line flow, it is unfortunate that limited laboratory space does not permit this wind tunnel solution approach.

This wind tunnel approach applied across a limited space lacking depth in front of the fume hood was apparently tried along with other supply configurations several years prior to 1979 in England[49], as is suggested by Figure 15, and represents a composite reproduction of two illustration from the referenced source (Figures 6.1 and 6.8 of the referenced source). Figure 15 illustrates three room air supply arrangements associated with best containment associated with a fume hood resulting from the way the hood make up air is introduced in to the space. The concept illustrating supply air being delivered through a perforated plate wall supply is similar to streamline airflow normally found in down draft laminar air clean rooms. This produces a wind tunnel effect that sweeps and flushes material in the room toward the fume hood. Continuous purges of a lab space is the desired goal with the purge air always flowing toward the hood sash.

Authors Morris, Klumb, and Cirincione correctly state in a recent publication[50] "Most laboratory workers are unfamiliar with the internal workings of their ventilation systems. Almost all laboratories use 'once through air systems' with 100% outside air make up systems." However, the authors incorrectly state, "On the average, all of the laboratory air is replaced with fresh outside air every 6 min. At this rate, laboratories should smell almost as fresh as the outdoors." The air in a laboratory is not purged with a single air change and replaced in a laboratory with each air change, unless the laboratory is constructed to be a wind tunnel, a situation similar to the early Weber laboratory/hood LAFCS. This speaks to the very heart of the problems with dilution ventilation versus containment ventilation[51].

Dilution dictates a required number of air changes in a laboratory in an order to keep fugitive emission concentration down. Fugitive emissions are emissions generated in and escaping a hood or emissions resulting from procedures done on a bench that should have been done within a hood. Hood or room exhaust airflow and room supply make up airflow must be maintained regardless of hood exhaust flow control, VAV or constant volume.

Our office has a full scale, four-fume hood working model mock, which we, and graduate ES&H students at Texas A&M University experiment in. This facility is well instrumented for precise and accurate air and velocity measurements as well as the instrumentation needed for the ASHRAE 110 test[52] (Miran 1A). Some time ago, we set out to validate our logic concerning Air Changes per Hour (ACH) and fugitive emission concentration in the laboratory workspace. By releasing SF6 into our test room at varying rates, in varying locations, and with varying and constant hood and room exhaust flow rates, we learned the following:

> Regardless of the number of ACH, if the SF6release rate was constant, the concentration of SF6 appeared to build up to some terminal value. The rate of build up depended on: (a) the liberation rate of SF6 (8,6,4 lpm), (b) the location of the emitter in the room, (c) the location of make up air delivered into the room (all being exhausted through one or more of four fume hoods in the room); and (d) the dilution rate (SF6 release rate/ACH).
>
> The terminal SF6 concentration value was fairly constant for a given liberation rate and dilution rate. Concentration differed in the room depending on whether the measurements were taken in dead spots or directly in the stream between the supply air and the fume hood faces. The room was not purged with each air exchange.
>
> If a fixed volume of SF6 was released at one time (gas injected into a balloon and the balloon punctured) and the ACH was held constant, the room concentration decayed with time and the time was different in some similar situations. The concentration did decay steadily after release of the emitter gas ceased. The time required for total flushing differed in each case, even when the liberation and ACH rate remained constant, some times as long as 12 to 24 hours.

The lessons learned from this experiment were:

> ACH does not guarantee user protection from fugitive emissions released from the hood or liberated in the room. To protect the users, contain the material in the fume hood, and when material is released in the room, vacate the room until a substantial time has passed and dilution ventilation in the room has purged the room of fugitive emissions. This assumes that the room remains pressure negative to the adjacent areas per NFPA 45.
>
> 100% containment is possible without fugitive emissions getting into the workspace where work is conducted in a properly designed and installed fume hood with ventilation containment control achieved with a properly operating LAFCS.

CONCLUSION: CONTAINMENT VENTILATION FIRST AND ENERGY SAVINGS WILL ALWAYS FOLLOW

The best design concept that emerged in the atomic era centered on the system that Weber and his peers worked to develop. These principles were:

> 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.
> An elevated air change rate in a laboratory space does not guarantee best containment capture and ventilation.
> Finally, if possible, provide comfort conditions for users working in the rooms that house the hoods. This latter situation however is not a code or safety standard requirement.

Laboratory designers, especially those more experienced with the atomic energy era, realized that containment ventilation which was developed for radioactive materials was better than dilution ventilation, at least for their purposes, and was best achieved by the following:

> Maintaining inferential fume hood face velocity constant by accurately and repeatable controlling hood exhaust flow with hood sash openings to produce consistent results regardless of static or dynamic hood sash position or airflow control system response dynamics. Use vertical rising sash hoods. With regards to face velocity and control with it, no one measures face velocity and thus controls with a measurement not taken. Constant inferential face velocity however, gained by setting hood exhaust flow with hood sash opening, or setting hood flow with sash position with vertical rising hood sashes "contained" best because of the "draw through" concept associated with it. Moreover, as taught by Clay**[53]**, the face velocity should always be approximately 100 fpm for best containment results and as taught by others, it is possible with best hood containment velocity being 100 fpm ± 20 fpm**[54]** across the hood sash opening.
>
> Always keeping the sash at its minimum opening and closed when a user is not present in front of the sash. This is best done by an automated system that guarantees this result and at the same time allows for "hands free" technician activities in the hood.
>
> Selecting hoods on the basis of their containment performance and aerodynamic characteristics, including airfoils, perforated type baffle plates or air filters that covered the back of the hood wall, curved sidewall sections, and full width transition (slot) to hood exhaust duct, plus other features. The hood must have an ability to "draw" air from the room space in a way that iso-kinetic flow, uniform across any sash opening is always maintained regardless of sash opening.
>
> Design the laboratory air supply systems and make supply flow track the exhaust flow in a what that supply flow does not cause disruptive drafts in the workspace that impact hood performance. The air system should also be designed to always purge the room air mass, transporting it to the hood face opening. This eliminates use of through the wall differential pressurization control of the supply air and the disruptive drafts associated with opening and closing the room doors while modulating ducted room supply flow.

Most of the factors examined and discussed were initially identified and published stemmed for the work of the atomic energy era. The conclusion concerning laboratory air flow systems and containment ventilation system employed in the atomic energy era however apply equally as well to chemical and biological fugitive emission problems:

This goal is best achieved with a properly designed and performing variable air volume (VAV) system and best results dictate use of an automatic analog 0-10 vdc electronic laboratory air flow control systems (LAFCS) for vertical rising sash fume hoods that meter and control each hood's exhaust flow rate with hood sash opening with true room supply flow tracking and independent temperature control. Analog fan static pressure controls and building flow-tracking controls must be included as a part of the system.

If VAV controls are used, true inferential constant face velocity at all sash positions to maximum hood containment with supply and hood exhaust flow control that is repeatable ±1% of set point, and with response time less than a second should be employed.

If Accu*Aire LAFCS and the Sash Positioner System or Sash Safety Assistant control features are combined in the same LAFCS application, energy saving results can be quantified and guaranteed as a byproduct of best containment ventilation. Furthermore, if attention is given to proper introduction of the supply air make up into the room and the fume hoods are selected on the basis of aerodynamic features with controls, including these LAFCS and sash position features allowing repeatable control of hood exhaust flow at all sash positions, maximum containment ventilation will always result.

If a properly designed and configured Sash Positioner System (sPs) or Sash Safety Assistant (sSa) is employed that helps minimize sash opening and close the hood sash when no one is in front of the hood, significant capture containment safety results. The sPs or sSa should also be configured to keeps the hood opening small, automatically opening to half sash height but allowing for a user to open the sash to full opening, again for maximum hood containment. sPs or sSa operation can include fire sensor and select chemical sensor activated purge control and should also include the automatic closing of the hood to produce the correct flow at any sash position when the exhaust fans belt slips or close the hood sash when the fan belt breaks or hood flow ceases.

For ultimate safety, the LAFCS should include a universal building automation system (BAS) interface allowing LAFCS non-interfering analog system perform monitoring through a universally accepted and standardized pear to pear LonWorks communication interface between any BAS system vendor with "fail-safe" single dedicated loop control always done by the analog control function should the BAS go "down." Problem and maintenance diagnostics reporting, on occurrence, through the BAS can easily be accomplished to ensure sustained high quality performance efficiency.

Finally, if a precise and accurate LAFCS and Sash Positioner System are control coupled and employed to control hood and room air flow, significant energy savings and first cost reduction can be guaranteed. A methodology for assessing hood use diversity and "active use" probability has been rigorously treated in two peer-reviewed publications[55] [56] with another paper, easier to understand, to be published in the September/October issue of Chemical Health and Safety, entitled Using Probability to Determine Air Flows for Fume Hood Design, for Duct System Sizing, Chilled Water Network Sizing, and the HVAC Central Plant Loads[57]. A freeware computer program, QLOADS Energy Savings Calculation Program[58], is also available at **www.accuaire.com/html/shareware.html**. The QLOADS Windows based computer program is used for projecting hourly HVAC peak energy consumption associated with 100% outside air laboratories having fume hoods. The program is accompanied by city weather data files and can be used to project outside air processing costs, savings and peak-demand sizing, based on constant air volume vs. standard variable air volume vs. automated sash variable air volume. Variables include period of fume hood usage, airflow profile or probability of use, and hours of operation.

WHAT ACCU*AIRE CONTROLS, INC. DOES AND HAS TO OFFER

Engineered systems specifically tailored to each application that . . .

> **Automatic analog electronic laboratory air flow control systems (LAFCS) for vertical rising sash fume hoods that meter and control each hood's exhaust flow rate with hood sash opening with true room supply flow tracking and independent temperature control.** Also included are analog fan static pressure controls and building flow tracking controls.
>
> **True inferential constant face velocity at all sash positions to maximum hood containment with supply and hood exhaust flow control that is repeatable** ±1% of set point with response time of less than a second! '
>
> **Sash Positioner System (sPs) and a Sash Safety Assitant (sSa)** that helps to minimize sash opening and close the hood sash when no one is in front of the hood. **Keeps the hood opening small for maximum hood containment!**
>
> Control loop panels furnished **with or without LonWorks** interface for communication to/from any BAS system vendor with "fail-safe" return always to the analog control function when the BAS goes down.
>
> **Fire sensor and select chemical sensor activated purge control** and our system's **ability to automatically close the hood to produce the correct flow at any sash position when the exhaust fans belt slips or close the hood sash when the fan belt breaks.**
>
> An engineering **ability to determining and guaranteed LAFCS diversity for maximize containment ventilation** with concurrent reduction of both equipment and duct sizes **to reduce first cost and guaranteed energy/operating cost saving**. No cold smoke, no linear valves, no snake oil and we can prove it!
>
> A **new vertical rising sash chemical fume hood configuration** with hood furnished by others and **ability to rebuild and modify hoods "in-place"** to include aerodynamically enhancements of the flow across the sash opening and through the cavity of the fume hoods. **Streamline airflow aiding in uniformity of hood face velocity that maximizes hood containment!**

Finally we design, build, sell and lease semi-permanent fully functional 8' wide and 55' long skid mounted laboratory units with up to 10 each interior flush mounted fume hoods that include all of the containment enhancement listed above plus more that guarantee containment ventilation safety at a level never before achieved and at the lowest first cost for any other similar type lab facility. We also do turnkey laboratory engineering and design for those who want their labs to work. **Maximum hood and room containment for the greatest user safety with the lowest first and operating cost…ever!**

THE RESULTS. . . **Maximum hood and room containment for the greatest user safety with the lowest first and operating cost…ever and better than any other offering on the market!**

*Swiki Anderson, Ph.D., is President of Swiki Anderson and Associates, Inc. (Bryan, TX) and Accu*Aire Controls, Inc. He can be reached at v. 979-779-6068, ext. 11; f. 979-779-6085, or at swiki@saai-svc.com or swiki@accuaire.com. For information concerning this engineering firm, visit* ***www.saai-svc.com****. For information concerning Accu*Aire Controls, Inc. and your nearest representative, contact Steve Summers at steve@accuaire.com or Soi Troung, at soi@accuaire.com and visit* ***www.saai-svc.com****.*

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Services, Oklahoma State University, Stillwater, OK 74078-0113, (405) 744-7241; or Larry Thompson, formerly Control Systems Manager, Physical Plant Services, Oklahoma State University, Stillwater, OK and now at Texas A&M University, (979) 862-7330 ; or contact Oklahoma State Board of Registration for Professional Engineers and Land Surveyors, Oklahoma City, regarding Case No. 98-41, regarding the Oklahoma Board vs. Robert Morris, R.H. Morris & Associates Configuration Management Consultants, Chatham, NJ.

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