FACTORS THAT WORK TO DEFEAT THE USE OF THE "THROUGH THE WALL" VELOCITY CONTROL CONCEPT IN FUME HOOD EXHAUST WITH SASH POSITION CONTROL

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Introduction

NOTE: "Through the wall [face] velocity control" is a term commonly, but incorrectly, used to describe a scheme for control of the average velocity of air into a fume hood through the sash opening by "side wall sensing". The velocity of air across one or more sensors mounted on, and protruding through the interior side walls of a fume hood,. is assumed to be adequate for indirectly controlling the face velocity across the hood sash opening, a different location, in proportion to the velocity signal across the side wall sensor(s).

There have been several attempts in the past five decades to utilize some sort of a sensor, mounted in the side wall of a fume hood, to indirectly measure, and then control, the velocity of air into the fume hood through the hood sash opening. While different types of sensors employed in different types of control schemes have been tried, the basic control function, and thus the needed containment goal, continues to be unrealized.

With this design, airflow across the sensor is normally introduced from the top of the fume hood, between the inner- and outer- hood walls and flows over the side wall sensor into the cavity of the hood. The driving potential for this flow path is the slight differential pressure that exists between the interior cavity of the fume hood and the room. In theory, the velocity of air through the flow path from the room, directly to the hood interior through the hood sash opening, should be somewhat proportional to the slightly lower velocity of air, through the more restrictive flow path from atop the hood, down through the hood side wall cavity and across the side wall sensor. Control of face velocity into the hood cavity resulting from the flow from the room is thus imputed to be indicative of the velocity of a single sensor mounted in the hood sidewall. All schemes using this concept, regardless of sensing mechanism or device, have commonly been referred to as the "through the wall" velocity sensing control schemes. Unfortunately, this approach is flawed because of several factors and does not produce consistently reliable control or containment ventilation results. Ventilation containment using this control scheme, or using this concept for providing alarm notification of unsafe containment conditions, most often does not produce needed and necessary results for proper fugitive emission control in the hood, especially with movement of the hood sash.

Fume Hood Set-up Procedure for Constant Volume Operation

Normal fume hood set-up procedure dictates that hood face velocity be established at some value when the hood sash is at its full open or extended sash position. Accepted industry practice [1] dictates that hood face velocity be established by dividing the hood sash opening into at least nine equal divisions and that face velocity then be measured at the geometric center of these divisions across the plane of the sash opening. The hood average face velocity, that is, the arithmetic mean of the measured face velocities at these equal points, is thus the basis for "average velocity". For most users, it is assumed that the desired face velocity is 100 fpm ±20 fpm, provided the velocity measured at the various points in the hood face is not less than 80 fpm. If it is less than 80 fpm, then the flow is normally adjusted upward so that the velocity measure at any of the points in the hood face is at least 80 fpm. This has long been the established procedure for setting flows with hoods served by a single exhaust fan.

Fume Hood Set-up Procedures for Variable Volume, Constant Face Velocity Fume Hood Operation and the Sidewall Sensor Impact

In an extensive series of full-scale laboratory mock-up tests[2] , all hood sash openings were divided to yield an array of sixteen (16) equal areas. In the last two of these efforts, two or more high quality vertical rising sash hoods from different manufacturers were used. Regardless of manufacturer, when a vertical rising sash hood was in its full open sash position, long term periodic fluctuations (i.e. - 30 seconds to 2 minutes) in individual velocity measurements at the probe points were observed. This phenomenon was observed to be more dominant closer to the hood side walls and diminished with reduced hood flow that occurred when the hood sash was closed. Later investigations confirmed that the phenomenon also occurs with horizontal sliding sash hoods, especially when a sash panel was open allowing air flow along one of the hood side walls.

Observation of smoke tracers, especially with vertical rising hood sashes in full open positions, indicated that multiple counter-rotating eddies existed across the hood face, always being more dominant along the hood side walls. This is illustrated in Figure 1; the strength of the eddy current is greater along the wall. This is illustrated in red and diminishing in strength first as illustrated first with magenta, then green. The same situation was also observed with horizontal sliding sash hoods, especially with full panel opening allowing flow along a side wall.

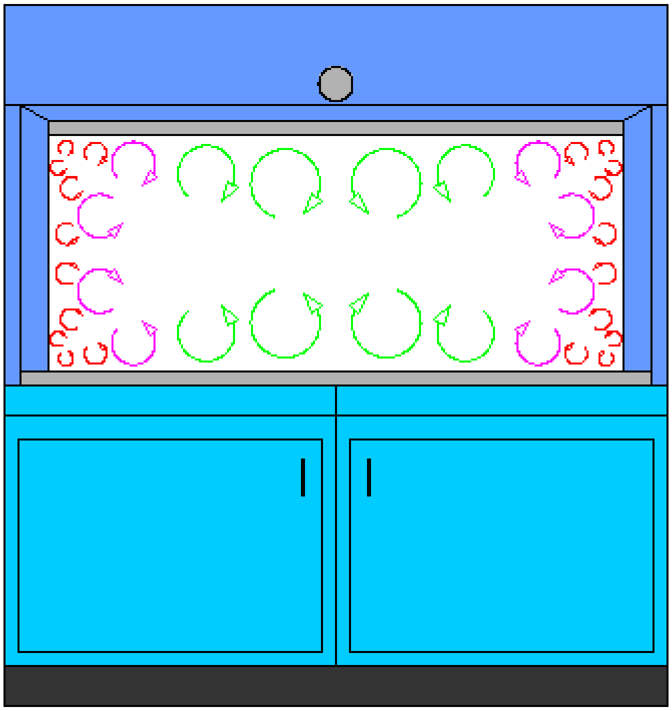


Figure 1. Secondary Flows in Hood Sash Opening

These eddies resembled an array of "mini-tornado" secondary flows (cork screwing eddies). They form at the hood face and then move into the hood cavity, diminishing as they extend along their individual axes, with the axis somewhat perpendicular to the plane of the hood sash opening. As smoke tracers were observed to move into the hood cavity, it appeared that the axis of the swirl shifted in a somewhat randomly varying orbital mode around what would have been the normal axis of the swirl of the "mini-tornadoes". Concurrently, the velocity signal measured from a sidewall mounted hot wire sensor under the influence of a dominant swirl varied in a sinusoidal manner, ±30% of mean value.

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. True uniform face velocity with isotropic turbulence slug flow into a hood is not possible to achieve. Moreover, the problem appeared to be greater with the hood sash in its full open position with eddy currents associated with secondary flows more pronounced at higher hood exhaust flow and face velocities. In addition, the size and strength of the secondary flows seemed always to diminish from the hood walls inward to the center of the hood opening.

How Secondary Flows Defeat Sidewall Sensing as a Means for Control of Constant Fume Hood Face Velocity with Variable Hood Exhaust Flow

Prandtl[3] hypothesized the cause of secondary flows in terms of an inequality of turbulent shear stresses normal to the mean velocity vector into the hood. This occurs as a result of the high shear stress gradient that exists along a channel wall, or in this case, the hood walls. The shear stresses in the air flowing along the wall, being of much larger magnitude than that encountered in the core region of the hood, gives rise to a very slight pressure gradient that decreases from the wall to the center of the hood. Secondary flows of differing strengths, according to location, are the result. The direction of the eddy currents, clockwise or counter clockwise, depends upon momentum dissipation per unit length as measured in various positions in the cross-section of the hood opening.

In 1961, the experiments of Gessmer and Jones[4] confirmed Prandtl's hypothesis regarding secondary flows. Additional support to Prandtl's hypothesis regarding secondary flows was presented by Einstein and Li.[5]

The existence of these secondary flows, especially along the interior hood walls impacts and defeats the performance of a velocity or pressure sensor when mounted through the hood wall. Positioning the sensor in the hood wall subjects it to the influence of these secondary flows. These secondary flows give rise to hunting of the hood exhaust flow, a condition that can be dampened out in the hood control circuit at the expense of controller sensitivity.

This phenomenon occurs when air enters the inlet of a non-radially symmetrical section, especially when the air is drawn into a rectangular type opening from an "at rest" condition. It has nothing to do with the accuracy or precision of a sensor used in the sidewall of a fume hood. These separate issues impact control system performance.

When a vertical rising sash hood is closed, especially in variable volume operation, the sash begins to act like an orifice and two things occur. First, with sash closure, the pressure within the hood chamber tends to become uniform, and is slightly reduced with variable volume operations. The number and magnitude of secondary currents and their strength is reduced. This secondary factor enhances the performance of a sensor mounted in the hood sidewall, regardless of type, as the impact of the secondary eddies is diminished. Secondly, as the sash closes the number of eddies that exist in the hood face is reduced.

The Controller Issue

Another factor of concern with laboratory airflow control schemes (LAFCS) has to do with Open Loop vs. Closed Loop and System Pressure Independent Control vs. Pressure dependent Control. These factors impact performance of the sensor/controller. They can negatively impact the needed (time) response speed of control loops and are entirely separate and distinct from the issue of sidewall eddy currents.

A closed loop control[6], 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 have been working on satisfying this goal and while some have succeeded theoretically, no means of measuring average velocity across the face of fume hoods has been achieved that poses no threat to the laboratory technician.

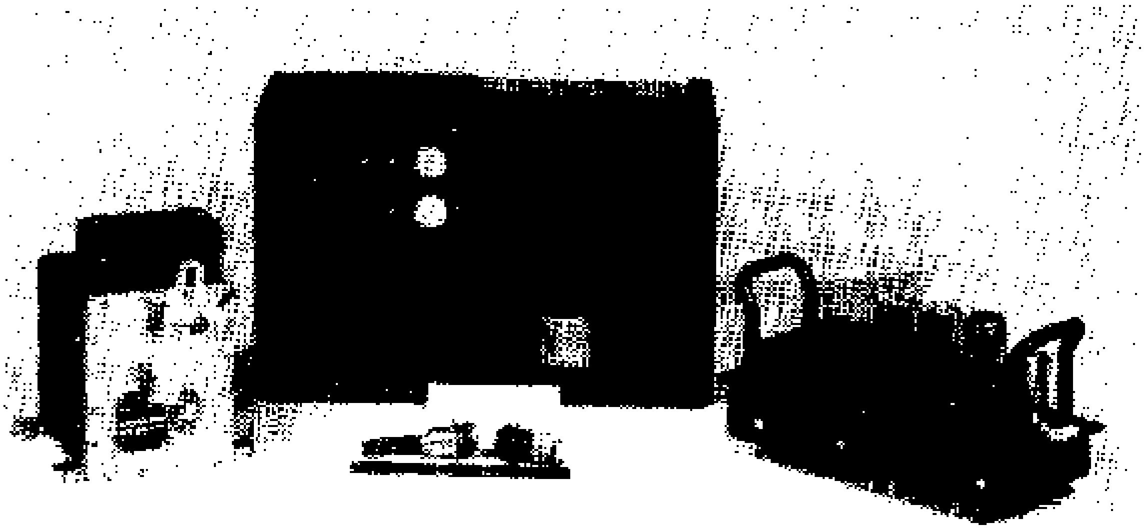
The Containment Goal: Historical Background

John J. Weber, Jr., a scientist who worked with atomic materials during a critical and significant wartime research effort in the 1940s, developed and published information concerning one of the first hood face velocity control systems.[7] The pioneer atomic research work done in the 1940s was done in un-air conditioned workspaces, with draw-through power supplied by a single exhaust fan serving each hood. The protection afforded to the user was solely because of airflow across the workspace and its entry into a fume hood through the sash opening. The ventilation system goal was protection of the user, achieved by an iso-kinetic velocity at the hood sash opening sufficient to capture and contain material in the fume hood. Weber's paper, titled "*A Mechanism For Automatic And Manual Control Of The Air Velocity At The Window Opening Of Fume Hoods*," can be reviewed at http://www.saai-svc.com/engineer/html/tech-notes.htm. This is suggested reading for any individual interested in laboratory containment safety.

Minneapolis-Honeywell Regulator Company’s Electronic Hot Wire "Through the Wall" Velocity Controller

Minneapolis-Honeywell Regulator Company developed what they called an "electronic" hot wire "through the wall" velocity controller which was described in a conference proceeding[8] and is illustrated in Figure 2. This represented the first "through the wall" velocity control system. Its description states:

> If a variable-volume air system is utilized, it would be desirable to utilize either the electronic or pneumatic type of hood-face-velocity-control .[9]



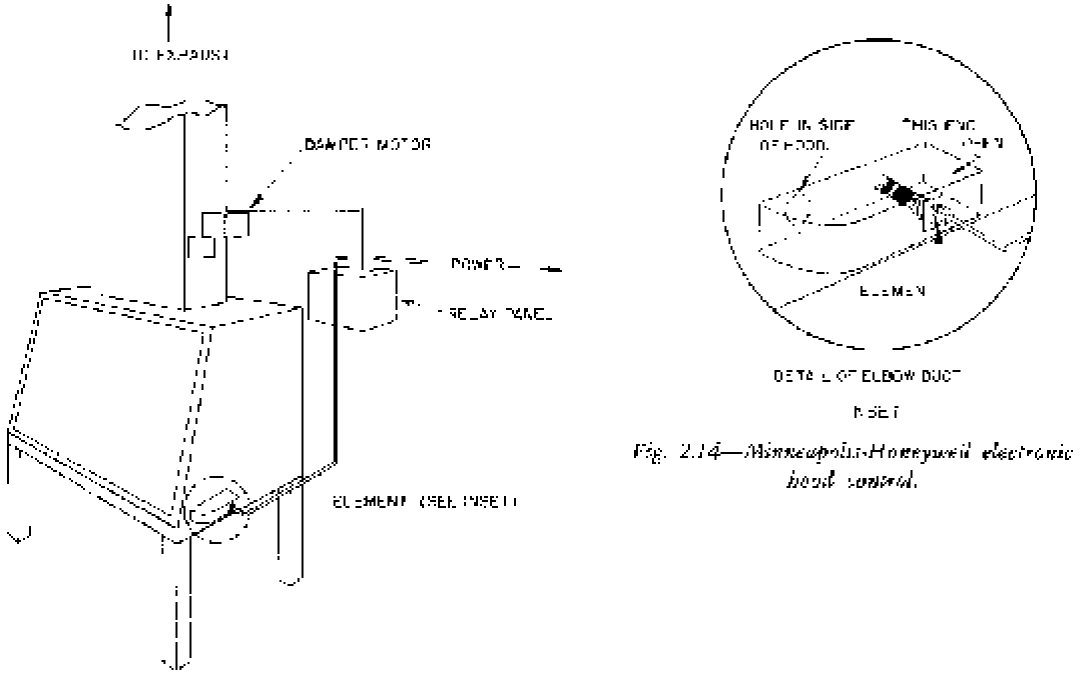


Fig. 2.14—Minneapolis-Honeywell electronic hood control.

FIGURE 2 Profiles of up-draft hoods, from Proceedings

This velocity controller was a "new kind of regulator…utilizing the cooling effect of air movement over a heater surface" and "involving only the use of a bridge circuit common to proportional control" [10] with the damper motive power in this case being an electric actuator.

Minneapolis-Honeywell's offering and how it worked is discussed in detail in an article by Homer B. Clay of the Company's Commercial Division. This article[11] , entitled *Laboratory Fume Hood Exhaust in Atomic Energy Laboratories*, is worth review because it objectively discusses the basic technical problem associated with controlling fume hood face velocity, regardless of the controlling mechanism. It is also worthy of review because it discusses and gives logical reasons why 100 fpm face velocity is a desirable and achievable goal, and average face velocities less than this magnitude are problematic.

For technical reasons, which are discussed below, the Minneapolis-Honeywell system that Clay discussed was never a success. The literature records and details its use at the Hanford Nuclear Energy Plant, in Richland, WA for a brief trial period.

Technical Problems: Fume Hood Face Velocity

In his *HPAC* article, Clay provides uncanny insight into the technical problems associated with various attempts and schemes to control fume hood face velocity and the need for 100 fpm face velocity. Within the limits of the technology, he stated,

> Laboratory fume hood exhaust systems usually require some form of regulation. Many means of accomplishing this have been devised.[12]

This is applicable to the arrangement illustrated in Figure 3 below which is reproduced from figure 2.1 the *Proceedings* of the 1951 Building Research Advisory Board conference.[13]

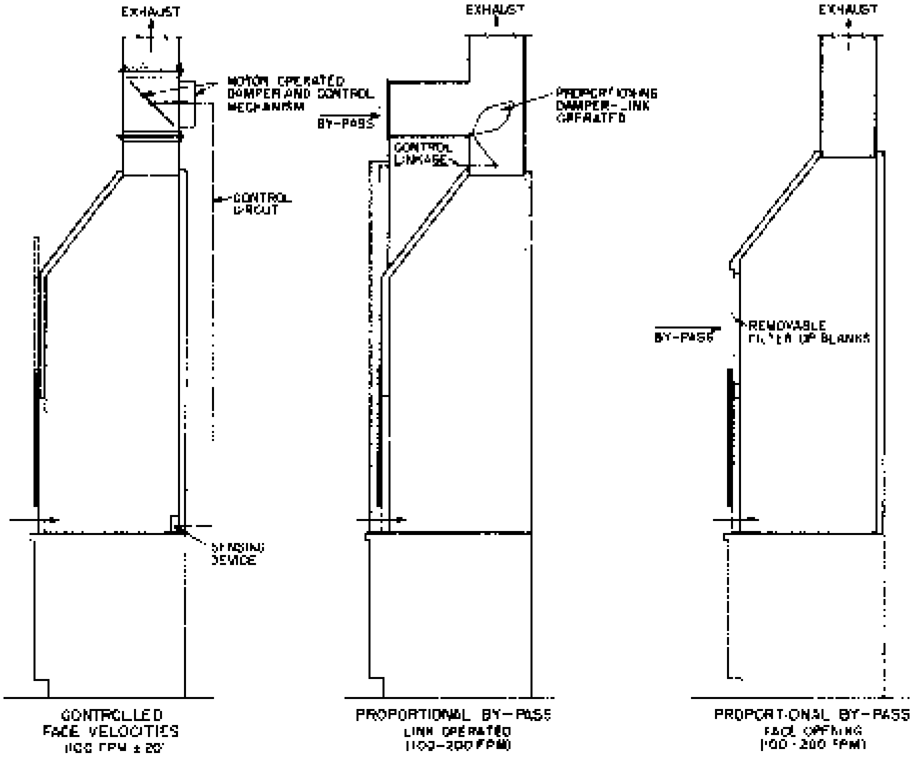


Figure 3, VELOCITROL™ Fume Hood Controller Typical Operation

The goal of a laboratory ventilation system was containment ventilation of fugitive material within the hood. And, while Weber with his hood sash position based, variable exhaust flow system had achieved this, the Weber scheme did not lend itself to anything other than a “pull only” laboratory air flow system. Attempts to provide containment ventilation of fugitive materials within a hood with concurrent “comfort conditioning” of the air supplied to a lab space via a forced (“push”) offered up a completely new set of challenges to the design engineer. Use of “push-pull” systems that allowed comfort conditioning of the supply air left – because adequate control systems did not then exist --- use of constant volume by-pass hoods or some means of throttling hood exhaust. Both schemes were directed however at maintaining constant hood face velocity at all hood sash openings.

The then recognized face velocity control application arrangements, illustrated in Figure 2.1 of the proceedings of the 1951 Building Research Advisory Board conference 12 illustrated these arrangements per Figure 3 below. Figure 3a represents the hot wire scheme and Figure 3b and c represent then recognized working by-pass type hood arrangements. Note the controllability limits and the fact that the by-pass portion of the hood in Figure 3c was the same height as the hood sash opening.

Clay also recognized the need to alarm or otherwise indicate a hood containment fault. He believed that any alarm should be based on airflow measurement.

> Unless the velocity is actually being measured, either in the form of a negative static pressure within the hood or as a measurement of the air movement itself, there is no guarantee of any airflow nor any warning if it ceases.
>
> Ideally, some method of constant measurement of air movement should be used. This measuring device may be used merely to operate an alarm if the velocity falls outside the specified limits, or to control the damper system so as to maintain the velocity within these limits. Accurate detection requires that the static head or velocity be measured within the hood itself. Then all other variables in the system are taken care of automatically, such as changes in static head due to large load changes in other branches of the main exhaust, changes in atmospheric conditions around the exhaust stack, or any other variables which might influence the air volume.[14]

Clay further believed that manual systems needed to be regularly calibrated:

> A manual system must therefore be readjusted at intervals with continuous monitoring to insure that sufficient velocity is being maintained. These intervals may be quite frequent, possibly every hour or so, or they may be days apart, depending on the type of work being carried on within the hood and the materials being released through the exhaust system.[15]

The Honeywell Velocitrol Concept

History has a way of repeating itself. In 1980, Louis J. Bentsen[16] applied Honeywell's new product, the VELOCITROL™ , to a fume hood to control hood face velocity by sensing hood sash position (see paper published in 1985). Without knowledge of Clay's earlier work, Bentsen proved the "through the wall" face velocity control concept at Exxon Research and Engineering Company's mock-up effort in an attempt to qualify the system for potential use in ER&E's Clinton Facilities Project. Like Clay's system, it was applied on a system static pressure dependent, closed loop control basis.

The initial trial and error tests were conducted on a low counter horizontal sliding sash hood.[17] In the course of these tests, almost 30 holes were drilled in the sidewalls of the test fume hood in order to find the optimum location to mount the VELOCITROL™ through the wall velocity sensor. In all cases, consistent hood face velocity results could not be obtained when the device was mounted in the sidewalls of the hood, and hood type (i.e., vertical rising sash or horizontal sliding sash) was not relevant.

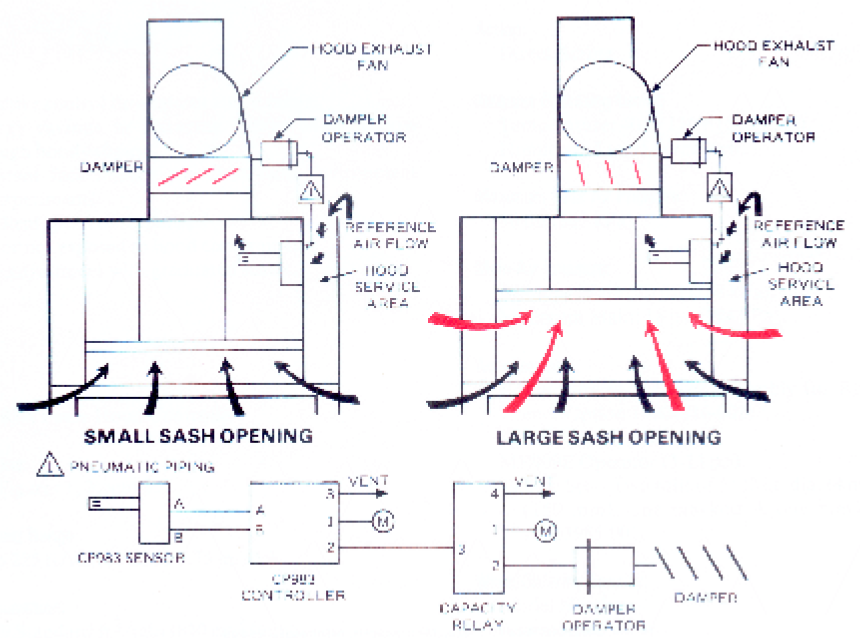


Figure 4, VELOCITROL™ Fume Hood Controller Typical Operation

The problem associated with hood type was discovered accidentally. Testing personnel observed that smoke produced by a lit cigarette placed on the top of the hood foil moved toward the back of the hood in a pattern like one would expect from a tornado, i.e., with the tail of the tornado corresponding to the back of the hood (z-axis) in (x-y) planes parallel to the face of the sash. This pattern was observed along the hood wall in a corner of the sash that was open. As the sash was closed, with smoke tracers produced in the same location, flow chaos was observed behind the closed sash. No streamlines caused by the smoke were observed. These findings indicated that the VELOCITROL™ device was subject to a very noisy (i.e., turbulent) signal; the signal-to-noise ratio was so large that the device could not function properly.

Bentsen recognized and addressed the problem imposed by the sidewall effect and chaotic flow situation by installing a "snout" that projected off the sidewall into the cavity of the hood. This allowed sensing flow relative to differential pressure to be measured with little or no eddy currents along the hood wall, especially in vertical rising sash hoods; it displaced the flow sensing path beyond the area of most significant eddy influence along the wall.

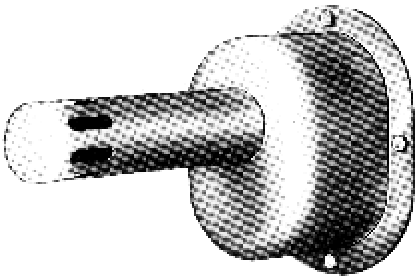


Figure 5, VELOCITROL™ Fume Hood Controller "Snout"

While the Honeywell VELOCITROL™ did not use the convective heat transfer basis to sense velocity across the sensor, the velocity control signal sensed across the device would shift significantly when something distorted the flow across the signal. This occurred most frequently when minute airborne matter adhered to the sensor or received tube elements employed in the device. For various technical reasons, Honeywell no longer markets or sells this device for this application.

The TSI Concept

In 1984, Dwayne Haggenstad[18] dealt with a problem that is common to many research buildings: when the number of hoods in a building increases, the net exhaust from the building increases, but the make up supply system of conditioned air does not. Supply system renovation costs and limited installation space dictated to Haggenstad an innovative approach to the solution. TSI, then a manufacturer of thermal anemometers was located in St Paul, MI and 3M sought TSI’s assistance in reducing hood exhaust air flow proportional to sash open position. TSI responded to the challenge, and began manufacturing a thermal-basis, temperature compensated "through the wall" fume hood face velocity electronic controller. Originally, TSI's sensor-controller sent a signal to a system of sinusoidal valves that either bled air off a damper actuator or opened main air to the damper actuator in an open control loop configuration. The original TSI system offering was applicable to fume hoods only and did not address the supply side of a laboratory air flow control system. This aspect of laboratory VAV type control was addressed somewhat later by TSI.

TSI applied a similar thermal airflow sensor in an attempt to maintain room-to-hall differential pressure. This concept used a sensor-controller to modulate the supply air damper(s) that provided make-up air into a room. Problems associated with the "room to hall differential pressure supply air control concept" are major and numerous and are discussed in "*Control Techniques For Zoned Pressurization*", ASHRAE Transactions, NT-87-04-1, http://www.accuaire.com/articles/zoned.htm. It is significant to note that no design engineers knowledgeable about VAV systems are now attempting to use the "room to hall differential pressure supply air control concept" to control room supply air flow into a laboratory.

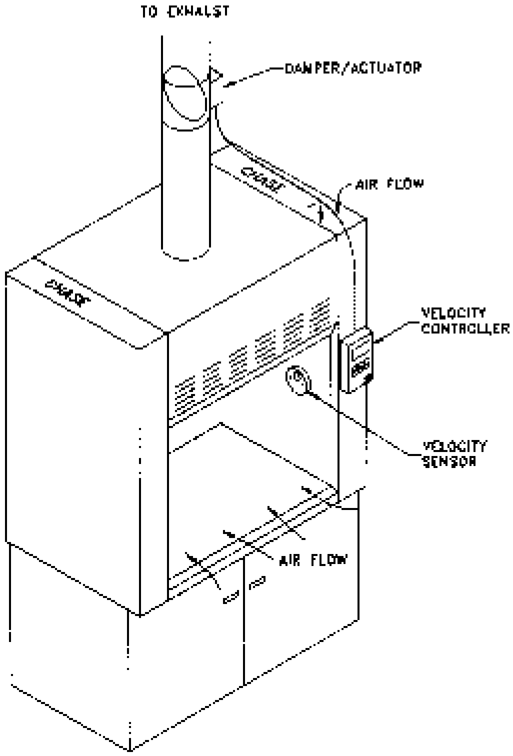


Figure 6, TSI Fume Hood Velocity Controller

The nature of the sensors that have been used in "through the wall" applications has also proven problematic. Thermal sensors depend upon a convective heat transfer principle to sense low-order air flow velocity. If dirt or other types of film accumulate on the sensor, the sensor's calibration shifts, accompanied by a detrimental shift in the control circuit response. This is a gradual process and is almost always undetected. For safe hood operation, much more frequent fume hood face velocity testing is required. This type of control device requires more maintenance than the "hood sash (opening) position" concept.

Open Loop Control Concept

Another major problem associated with all "through the wall" type face velocity sensors and controllers stems from employment of an open loop control concept that all of the above schemes employ [19] With this design, the control action is to open the valve or damper to whatever limit the controller is calling for as required. There are no flow "stop limits". The open loop schemes directly modulate flow according to valve position. Closed loop flow control valve positioning schemes meter and regulate flow regardless of differential pressure across the valve. This is significant, especially in ganged fume hood exhaust systems where improperly controlled flow can detrimentally impact containment of other hoods on the same exhaust trunk system.

Negative Flow Path Impacts

Another detriment to the "through the wall" type velocity sensor also stems from flow path considerations. Early but disastrous attempts to use this sensor concept occurred when the flow path was from the ceiling cavity space above the hood, through the cavity between the hood interior and exterior walls, across the sensor, and into the hood interior cavity. The very low-order differentials (driving) pressure between the room and hood interior cavity necessary to produce 100 fpm face velocity (approx. 0.000625 in. W.C.) can be and most often is different from the pressure that exists between the above ceiling cavity into the hood and the room cavity into the hood. This problem is especially significant when a hood has an architectural skirt installed above the top of the hood extending into the ceiling cavity before ceiling tile is installed. While this is remedied by creating a flow path across the sensor into the room, this also imposes a greater differential pressure resistance than that associated with the path directly between the room and the hood interior. Figure 7 illustrates this "special flow path" arrangement employed with the Accu*Aire Controls' Type C dual hotwire sensor.

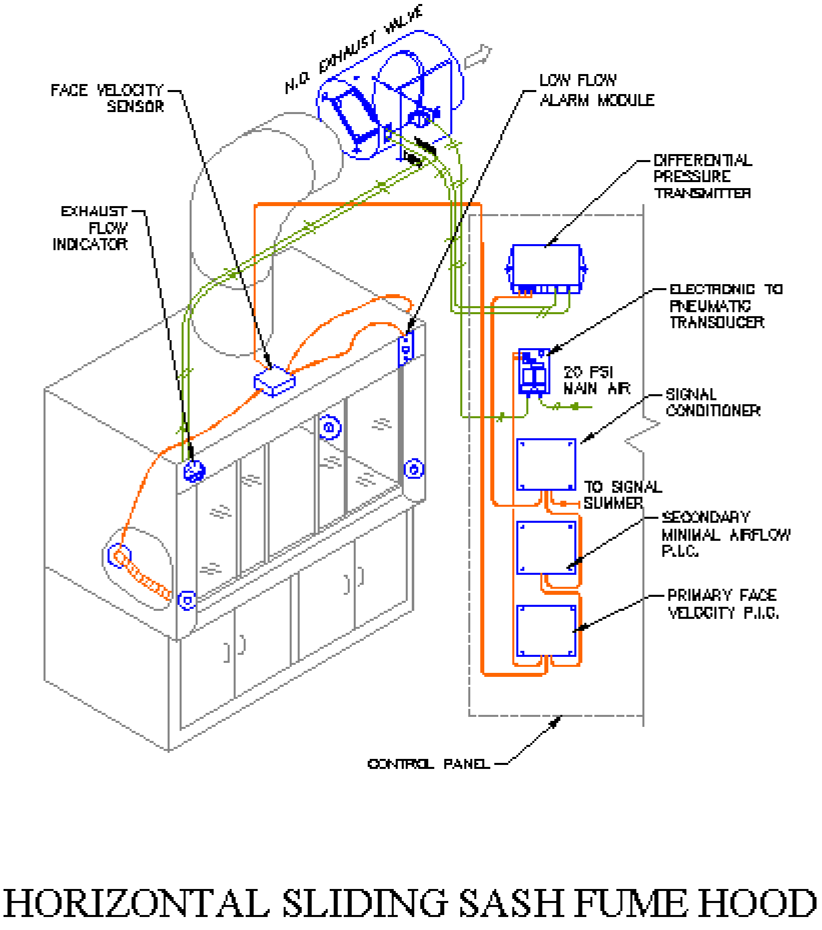


Figure 7, Accu*Aire Controls' "TYPE-C" Control Scheme

Minimum Airflow With a Closed Sash

It is anticipated that a major code setting body will soon be recommending a minimum airflow for VAV fume hoods at 50 CFM per foot of hood width, or 20 percent of full open required CFM. Most "through the wall" face velocity control systems do not meter or control the exhaust airflow rate leaving the fume hood and thus, do not have a way of setting the minimum CFM to a particular value. With a typical fume hood with the sash closed, the minimum airflow might be as low as 15 percent of full open CFM or 30 CFM per foot of hood width.

The Accu*Aire Averaging Sensor Concept

There is a place for the "through the wall" concept for hood exhaust flow control. It is with the use of horizontal sliding hood sashes (rather than vertical rising type sashes) or "combination type sash" (horizontal sashes within a vertical sash) hoods. In these applications, Accu*Aire Controls[20] has used two or more thermal sensors mounted in the hood wall (rather than a single sensor). This is illustrated in Figure 7. The signals from these signals are averaged to produce a much more stable and representative feedback control signal. Testing has indicated that there is a vast improvement in hood performance when two sensors are used, rather than one. Diminishing improvement is gained when the number of sensors is increased, i.e., three rather than two, four rather than three, etc. The only drawback to the multi-sensor approach is that while system control performance greatly improves, component costs also increase. Unfortunately, many buyers lose sight of the goal – proper control of hood face velocity under all operating circumstances. And, system first cost most often overrides performance considerations and gains associated first cost increases.

Accu*Aire Control schemes, because they incorporate and set hood flow on the basis of metered hood exhaust, ensures that a minimum airflow is maintained when the hood sash is closed. The minimum flow value, depending on owner dictates, is typically between 30 to 50 CFM per foot of hood width .

Other Factors Impacting Control System, Performance

In conclusion, it should be noted that the above discussion does not address the supply side control problems and impact on hood performance, hood or room control loop time responses, and a vast number of other factors that can influence hood and containment ventilation performance. Many of these factors are as important, if not more important than the negative through the wall sensor impact discussed and presented above.

1. SCIENTIFIC APPARATUS MAKERS ASSOCIATION (SAMA), **Standard LF 10 – 1980**; section 5.2, Face Velocity Guide; subsection 6, FUME HOOD EVALUATION IN A TEST FACILITY, and E1.2.1, Careful selection of face velocities.

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

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

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11. Ibid

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12. Ibid, page 80

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13. Proceedings, "Laboratory Design for Handling Radioactive Materials," Research Correlation Conference, Building Research Advisory Board Conference Report No. 3, National Research Council, National Academy of Science, November 27 and 28, 1951, published May, 1952; p. 27

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15. Ibid, p. 80

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16. Louis J. Bentsen, Senior Applications Engineer, Honeywell Commercial Division, Inc., Arlington Heights, IL. (retired) *New VAV Controls for Fume Hoods;* HEATING, PIPING & AIR CONDITIONING, February, 1985; pp. 67-70.

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17. Anderson, Swiki, et al.; "Laboratory And Fume Hood Airflow and System Control Study", Exxon Research and Engineering Company; Plant Operations Division, J.H. Farho supervising; December, 1980. Also see "***Laboratory Fumehood Control***," HEATING, PIPING & AIR CONDITIONING, Volume 56, No. 2, February, 1984, pp. 85-89, with J.H. Farho and W.M. Goryl.

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18. Dwayne Haggenstad of Central Research Engineering, 3M in Saint Paul, Minnesota

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19. **1991 ASHRAE APPLICATIONS HANDBOOK**, Chapter 41, AUTOMATIC CONTROL, page 41.1.

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20. Accu*Aire Controls, Inc., "TYPE-C" control scheme

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