CONTROL TECHNIQUES FOR ZONED PRESSURIZATION

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ABSTRACT

This paper briefly discusses the application of zoned pressurization in buildings and how it is being accomplished. Special emphasis regarding control requirements commonly found in clean rooms, hospital operating rooms, toxicology facilities, wet chemistry labs, or buildings of other demanding constraints are presented and discussed. The two basic control methodologies, flow tracking and differential space pressurization, are presented, and the contrasting differences between the two types of control schemes are discussed. Test results associated with a few limited situations wherein zoned pressurization has been used in facilities are presented as examples of the two methodologies.

INTRODUCTION

As our level of understanding relative to complex biological and chemical processes continues to increase, greater restraints and demands are placed on the engineering profession to improve control of the environment in the workplace. Although the restraints are numerous, complex, and often interrelated, significant control system improvements have been made over the last ten years. These improvements now allow knowledgeable engineers greater flexibility and precision in attaining a specific desired system response than has heretofore been possible. This paper focuses on two control schemes for zoned pressurization and presents several ways of accomplishing zoned pressurization control. It also presents limits and constraints associated with the schemes discussed and contrasts differences between them. Finally, it presents typical results that have been attained with the designes presented.

BACKGROUND

Figure 1 illustrates a control volume in a space that is typical of a conditioned zone in a building. The concepts presented throughout this paper are applicable to spaces where infiltration or exfiltration into the space is desired. For discussion purposes, a wet chemistry laboratory where infiltration into the apace is desired is used as one of the control volume illustrations. As an example of a space where exfiltration from the space is desired, an electronics clean room application is discussed.

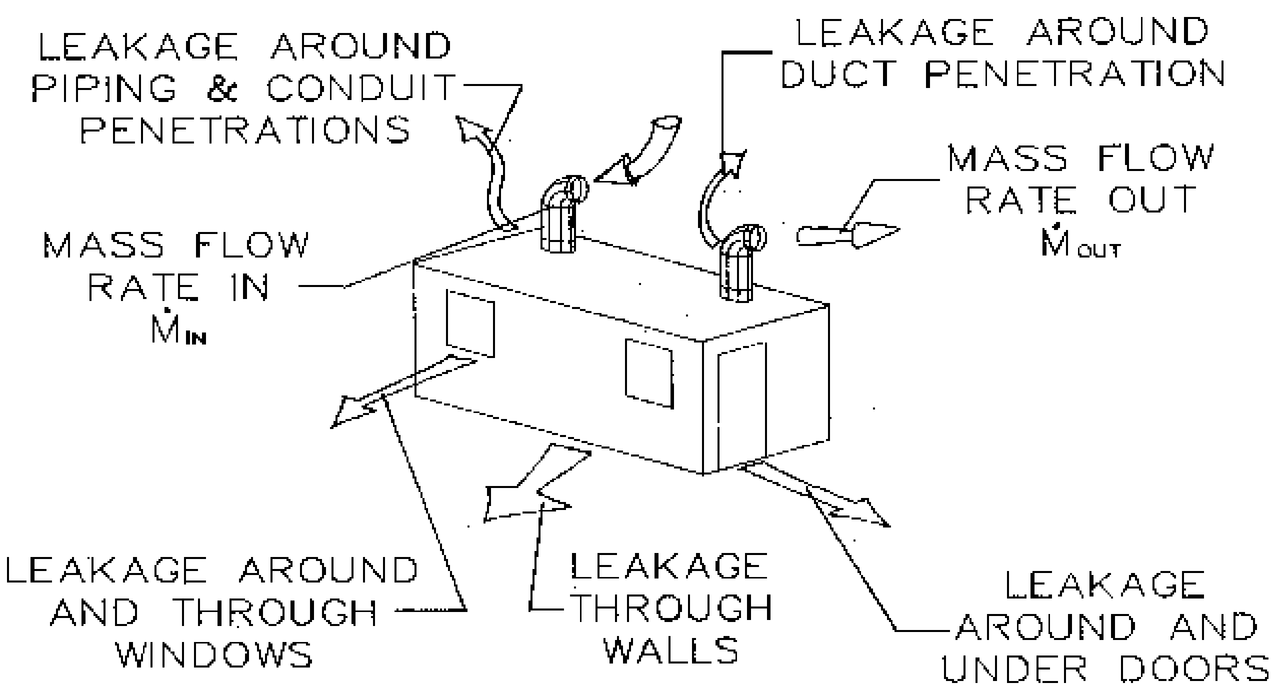

FIGURE 1
Typical zone conditions

If discussion is limited in scope to airflow into and out of the space where leakage is allowed, the mass flow (M) equation for the space can be written as

(1)

If it is assumed that the density of air is reasonably constant and the pressure state of the gas is approximately atmosphere, then Equation 1 can be simplified and reduced in form and written as:

(2)

where

where

= Volumetric flow rate

= mean velocity of the fluid

= area of the openings into or out of the space.

Moreover, on the basis of the Bernoulli equation, it can be shown that airflow leakage from the control volume can be characterized on the basis of Equation 3 as follows:

(3)

Where the Cv factor characterizes the room leakage or, as referred to by some sources, "room porosity;" it is a function of room construction. In all cases, since the room Cv factor is fixed and invariant with time, examination of Equation 3 suggests two techniques for satisfying the constant zone Cv factor constraint, namely:

- Fix the room supply and exhaust airflow rates at different levels and, in doing so, create a differential pressure across the control volume that is characterized by the room Cv factor. In this situation, leakage depends upon the difference in flows supplied and exhausted from the space; this difference establishes a pressure differential between the control volume and its surroundings. This concept will be referred to hereinafter as *flow synchronization*.
- Fix either the supply or the exhaust flow rate at a constant value and, by sensing the differential pressure across the control volume, change the exhaust or supply flow rate to maintain the differential pressure across the control volume. This concept will be referred to hereinafter a *differential space pressurization*.

The two methods identified above are the two basic control methods for achieving zoned pressurization. Application of a particular method to a particular situation demands some quantification of expected results.

THEORETICAL EVALUATION OF EXPECTED RESULTS

If the room Cv factor is fixed, Equation 3 can be rewritten as:

(4)

If Equation 2 is incorporated into Equation 4, Equation 4 can be rewritten as:

(5)

where $\mathbf{K = Cv^2}$. Several conclusions can be drawn from examination of Equation 5 as follows. If Equation 5 is expanded in differential form to yield Equation 6 and Equation 5 is subtracted from it, as follows, Equation 7 results.

(6)

(5)

(7)

If Equation 7 is normalized, Equation 8 results

(8)

or

(8a)

Equation 8 suggests that a slight change in leakage rate must be accompanied by a significant change in zone pressurization. As an example, a 1% Increase in leakage rate (**/** $_{\textbf{leakage}}$) will result in at least a 2% change in pressure differential (i.e., **d P / P**) if the room Cv remains constant.

PRACTICAL CONSTRAINTS

In addition to the above theoretical considerations, there are some very practical constraints associated with application of the two methodologies -- *flow synchronization* vs. *differential pressurization* -- for attaining a particular zone pressurization level:

It is very difficult to control the sources of room or zone leakage during building construction. Because of this, it is very difficult to quantify simultaneous flows and interior-to-exterior zone differential pressure at some fixed level prior to space construction. Any engineer who simultaneously specifies a differential pressure across a wall and flow rate through a room wherein both are controlled by the same control loop has over specified his system and has failed to understand this problem.
If proportional-only controls are utilized for this purpose, hysteresis in damper positioning with control signal occurs because of the proportional offset behavior encountered with this type of controller.
Control system response in time is finite.

ROOM-TO-HALL DIFFERENTIAL PRESSURIZATION CONTROL

The first two constraints identified above are illustrated below by data that were taken in a two-hood laboratory module wherein hood exhaust was controlled by hood face velocity and room supply was controlled by room-to-hall differential pressurization. The control scheme is illustrated in Figure 2. Table I represents data that have been recorded for this situation and indicates several items of significance as follows:

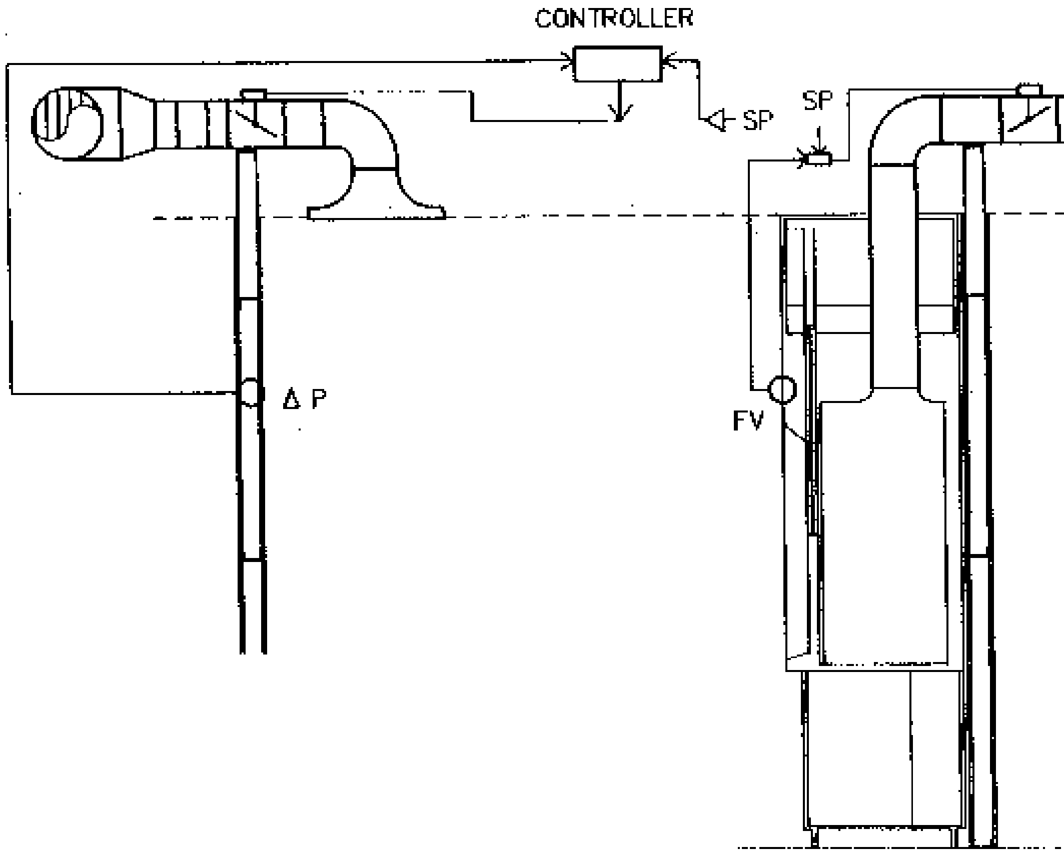

FIGURE 2
Typical VAV hood exhaust system
(space pressurization)

The arithmetic mean value calculated for room Cv factor was 3166; in all cases, however, the room Cv factor remained constant. This factor indicates "noise" that was being sensed in the primary signal or a problem in the control loop or both.

While it is not shown and is not now available, the analog room-to-hall differential pressure (i.e., primary signal) recorded with time for each sample exhibited continuous "hunting" during the recording of each of these independent samples. These independent samples (i.e., the data tabulated for each of the 16 entries in the table) represent the arithmetic mean values associated with 100 sequential (with time) sample values. Accordingly, presentation of the averaged value data may be somewhat misleading relative to the physical behavior exhibited by the control system, and the data cannot be interpreted to reflect a particular control problem source.

It is interesting to note that the maximum, mean, and minimum values, along with their respective variances, were:

Minimum		**= -0.0090 in H2O**
		= 210 CFM
	Cv	**= 2213 (-954, -30% of mean)**
Mean		**= 0.0186 ± 0.0067 in H2O**
		= 426 ± 38 CFM
	Cv	**= 3166 ± 86.43**
Maximum		**= -0.0400 in H2O**
		= 664 CFM
	Cv	**= 3924 (+758, +24% of mean)**

A somewhat parallel topic which is associated with the differential pressure control concept as discussed herein, is data presented by Klote and Fothergill in their Design of Smoke Control Systems for Buildings (Klote and Fothergill 1963). They expressed their flow equation as:

(9)

where

= the volumetric airflow rate, cfm,

= the flow area, ft^2,

= the pressue difference across the flow path, in H2O,

and

Kf = a coefficient, which they assigned a value of 2610.

The coefficient of 2610 is obviously unique to their situation, and the contrast between the data presented in this paper and as associated with the work of others serves to emphasize that constructors generally do not or cannot exercise a great deal of control over room Cv factor during construction.

In their thesis on Smoke Control in Fire Safety Design, Butcher and Parenell (1979) formulated the same mathematical problem with an area consideration similar to that exhibited in Equation 9. In dealing with sizing the required airflow needed for zoned pressurization, they state (Butcher and Parenell 1979. p. 152):

> In calculating the air supply needed for a pressurization system two major assumptions have to be made. These are:
>
> The leakage areas of the components (doors, lift doors and windows) which have been used in the calculations will apply to the components concerned when the building is completed.
> No unidentified leakage areas out of the pressurized spaces are present.
>
> In the face of these two necessary assumptions, it is suggested that an allowance of 25% should be added to the calculated values of the required air supply. It should be emphasized that this addition is suggested to make allowance for uncertainties in the values of the leakage areas which have been assumed. It is not intended as an allowance to take account of leakage in the supply ducting.

Few other estimates of suggested allowances are offered in the literature for sizing the airflow needed for differential space pressurization control.

FLOW TRACKING PRESSURIZATION CONTROL

In contrast to the data presented in Table I for the control scheme illustrated in Figure 2, Figure 3 illustrates a different room subject to flow tracking pressurization control wherein supply flow was controlled, coupled, and regulated by room exhaust flow. Table 2 and Table 3 represent data that have been recorded in this room, wherein fume hood exhaust was controlled by a hood face velocity sensor and room supply airflow was controlled and reset to track hood exhaust at a value less than hood exhaust. The difference in the data stems from the fact that two different manufacturers supplied the control systems and the set-point values were different in both situations.

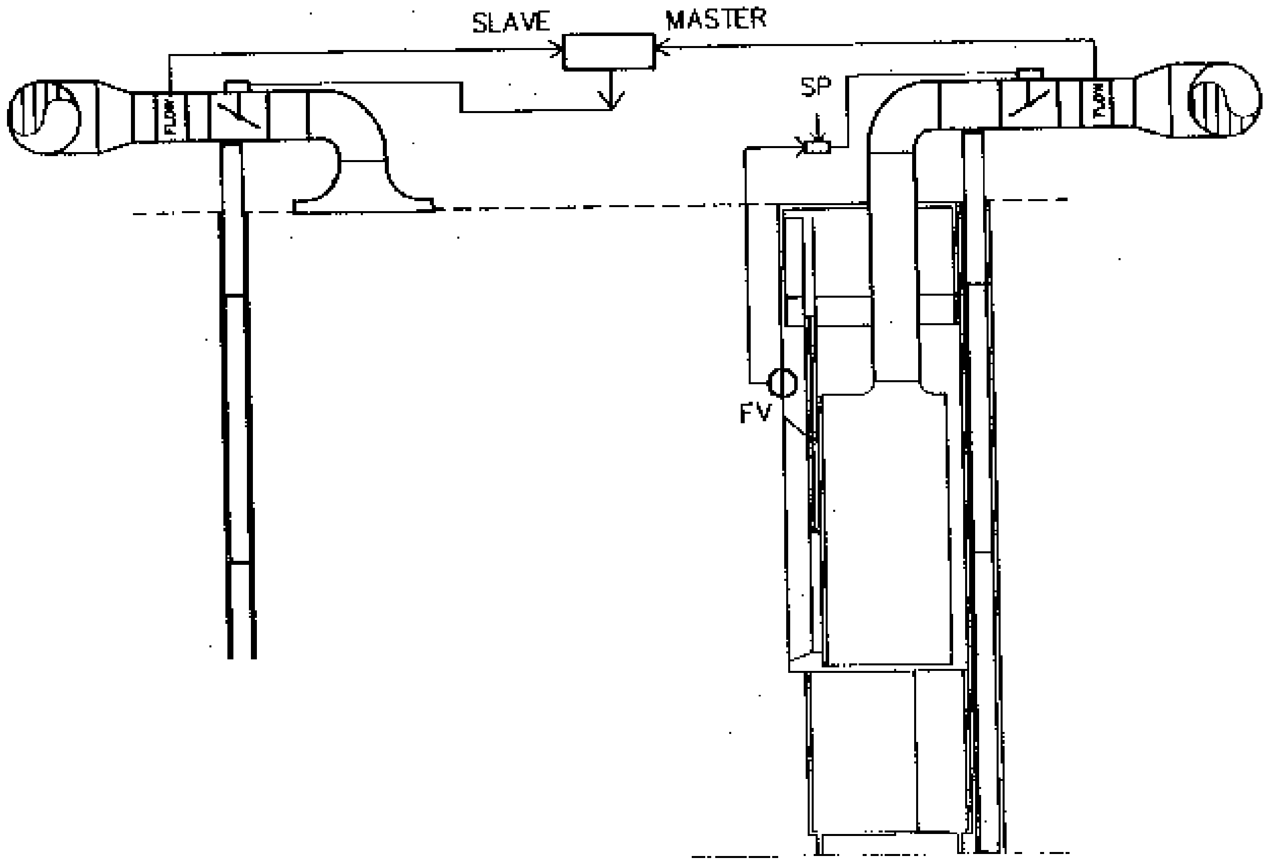

FIGURE 3
Typical VAV hood exhaust system
(flow synchronization)

Two sets of arithmetic mean values are presented for room Cv factor (i.e., 1706 and 1530). In this case the Room Cv factor also remained constant. Again, this variation indicates flow "noise" or a slight instability with the control loop as previously discussed.

Figure 4, however, illustrates an analog record of supply and exhaust flows; it clearly indicates that the difference in Cv factors identified above may be attributed somewhat to factors beyond those associated with the control elements that impact control loop performance. The flow signal in this case is from a differential pressure signal from a transducer that has been "square rooted" and multiplied by the duct cross-sectional area (a constant). Thus, since the duct area is constant, the error in Cv is partially attributable to a disturbance in the flow caused by the flow sensor element, turbulence in the fluid stream at the sensor, and perhaps other forms of "noise" in the control loop.

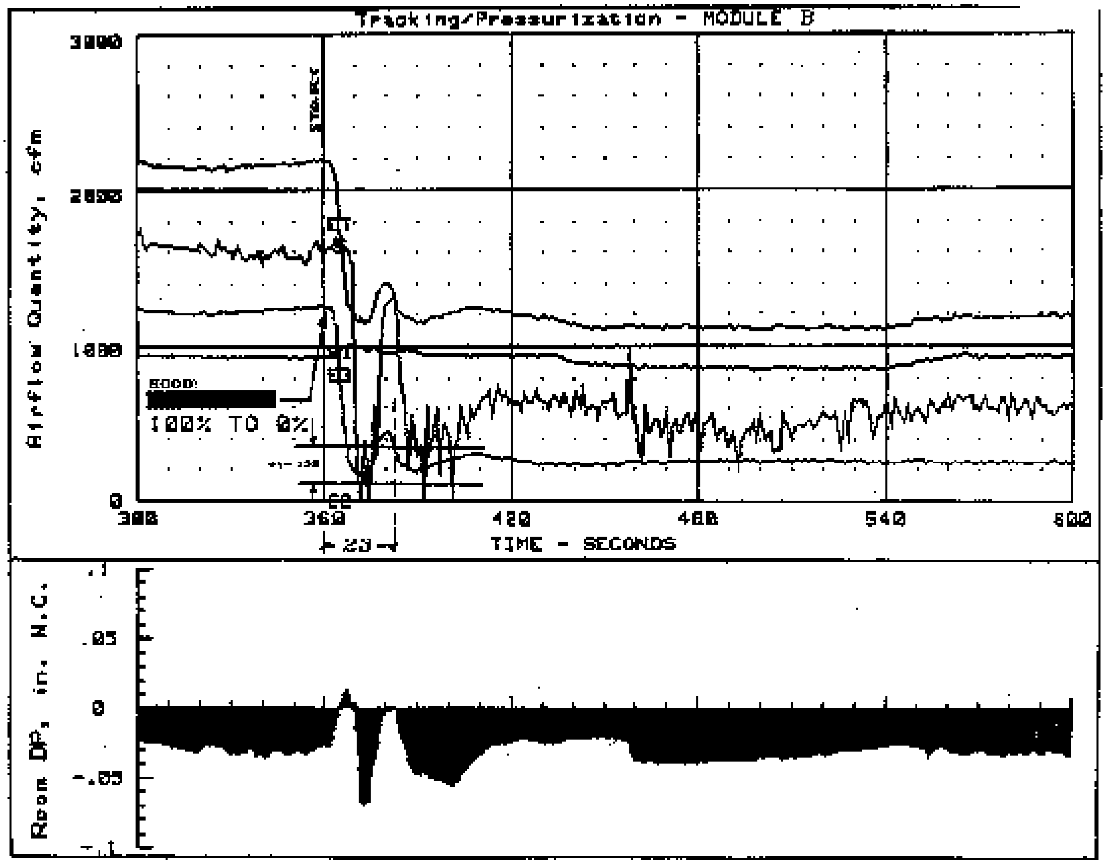

FIGURE 4
Real time airflow tracking

It is interesting to note that the maximum, mean, with their respective variances, were:

		Control System Manufacturer #1		Control System Manufacturer #2
Maximum		**= -0.0067 in H2O**		**= -0.0025 in H2O**
		= 508 CFM		**= 386 CFM**
	Cv	**= 1993 (+286, +17% of mean)**	**Cv**	**= 2465 (+715, +41% of mean)**
Mean		**= -0.0632 ± 0.0002 in H2O**		**= -0.0155 ± 0.0037 in H2O**
		= 428 ± 68.5 CFM		**= 190 ± 85 CFM**
	Cv	**= 1706 ± 273**	**Cv**	**= 1530 ± 999.6**
Minimum		**= -0.059 in H2O**		**= -0.0009 in H2O**
		= 358 CFM		**= 73 CFM**
	Cv	**= 1383 (-323, -19% of mean)**	**Cv**	**= 544 (-1185, -69% of mean)**

CONTROL SYSTEM RESPONSE TIME IS FINITE

The data presented in Figure 4 suggest constraints that must always be considered in specific control types regardless of application, namely: what is the response time of the system? Figure 5 illustrates a typical block diagram of a control loop used for this control problem.

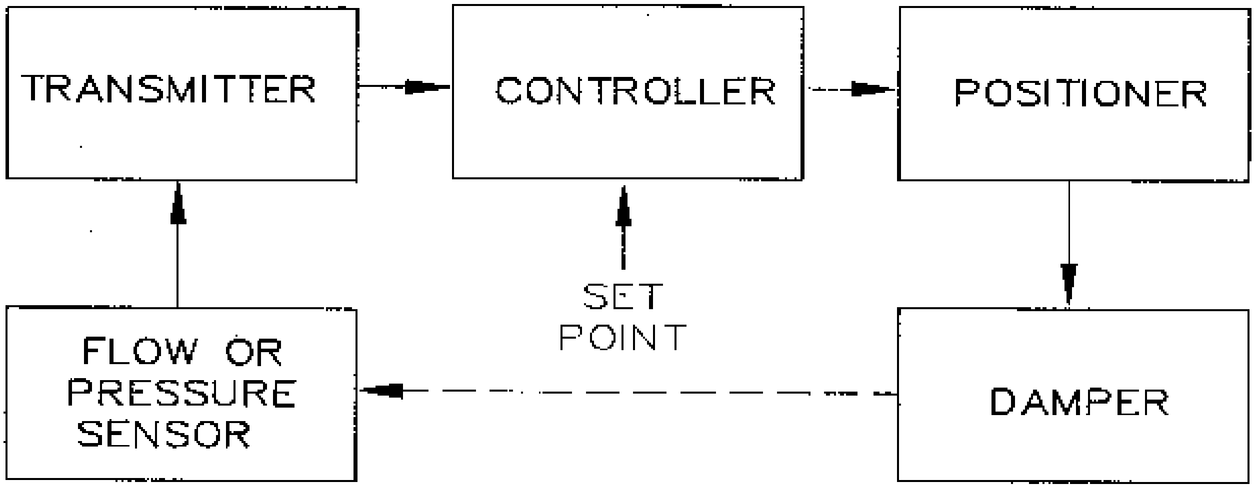

FIGURE 5
Typical control loop

Since the flow/pressure sensor, transmitter, positioner, and damper cannot be "tuned," the controller is the only device in the circuit that can be adjusted and thus used to yield a particular control circuit time response. The ideal response to a step change in set point is where the control variables (flow or pressure) instantaneously track the change in set point as illustrated by the curve labeled "A" in Figure 6.

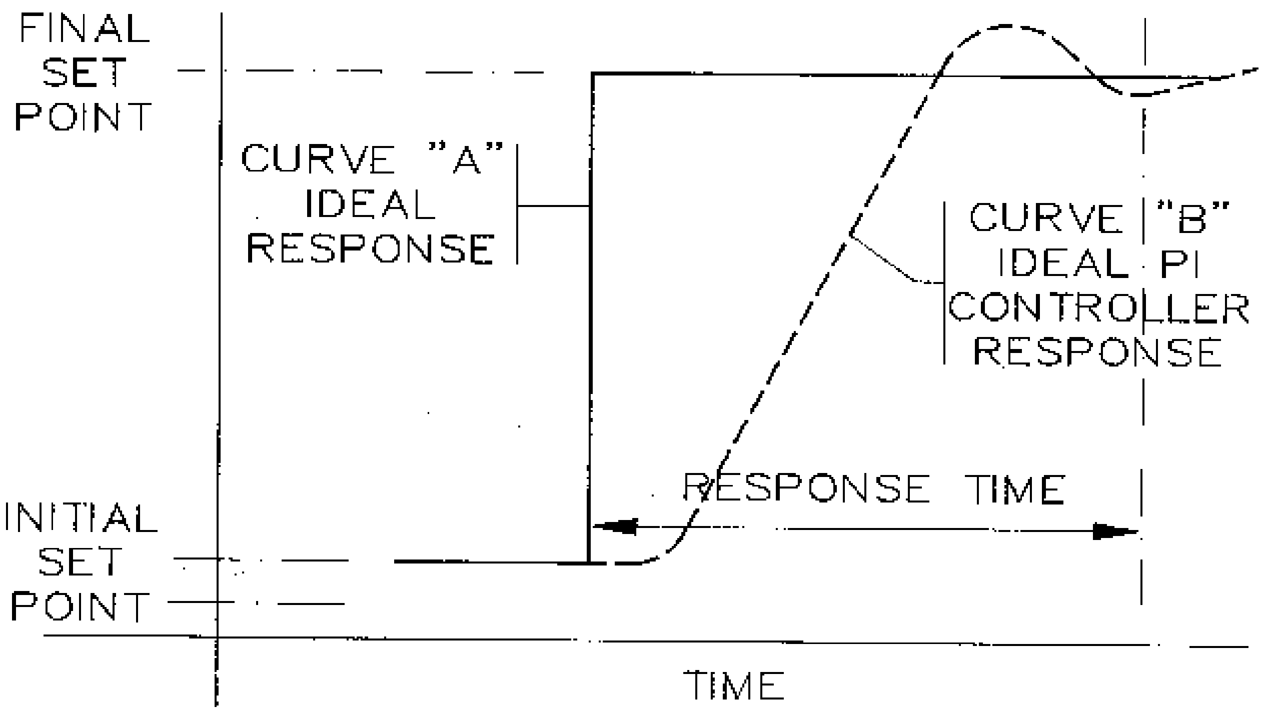

FIGURE 6
Typical controller response

Unfortunately, the dynamics of control circuits will not allow for this, and the more typical control response depicted by curve B occurs. Past experience with numerous control circuits manufactured by various suppliers suggests, on the basis of acquired real-time data, that the minimum time lag for a control system used in zone pressurization is on the order of 15 to 25 seconds. This response typically must be achieved with a two-mode controller (proportional and integral; derivative rarely and only with high-speed electronic controls). The problem is what associated occurrence takes place with the system during the time the control loop is cycling?

As an example, with reference to Figure 4, when the sash associated with fume hood no. 3 was closed, the control loop momentarily allowed the room to go slightly positive. This is illustrated by the positive pressure excursion exhibited with the real-time room-to-hall differential pressure vs. time plot data. If the doors into the laboratory were closed when this occurred, the occurrence would be of little consequence in most situations. However, if the pressure excursion was associated with a Class 1 clean room that emptied into a personnel corridor, the situation could prove considerably more problematic from a process standpoint.

CONCEPT-APPLICATION TO NEGATIVE SPACES

Consider next the application of these two basic control concepts (i.e., *flow synchronization* vs. *differential pressurization control*), which are best illustrated by physical examples. The first one is a "negative" space. This consideration applies to such applications as wet chemistry laboratories wherein flammable materials are used or stored and such spaces "… shall be maintained air negative to the corridors or adjacent non-laboratory spaces during laboratory operations" (NFPA 43 1975; pp. 45-31 through 45-32).

Hood Face Velocity - the Exhaust and Controlling Aspect. This situation is illustrated by Figures 2 and 3. Hood face velocity is the dominant control consideration in this situation, and it is determined and maintained by hood exhaust rate. It has been an accepted practice in the past, to establish a constant exhaust flow rate from a hood at maximum normal sash openings. By making the hood's exhaust flow rate respond to a variable hood sash opening, such that hood face velocity is maintained constant at all hood sash openings, significant energy avoidance savings and, in some cases, better entrainment across the hood sash opening is always achieved.

System Control - the Supply Aspect. In order to maintain the laboratory space at a pressure that's slightly negative to adjacent corridor way spaces, the supply flow into the laboratory must be maintained at a lower volumetric flow rate than that being exhausted from the space. Thus, infiltration at some unspecified level into the laboratory space is achieved. Applications of the two basic control concepts to laboratories via "differential space pressurization" vs. "flow tracking", offer both significant differences and potential benefits to a user, depending upon what is to be accomplished. The major differences are summarized and contrasted in Table IV.

Occupant Comfort - The Constraints. Occupant comfort, while subordinate to the two above factors, dictates that reheat of the supply air take place when ventilation requirements exceed the conditioned airflow requirement. Conversely, if the conditioned airflow requirement necessary to offset the space-cooling load is insufficient, the exhaust airflow rate from the room and the supply airflow rate of conditioned air into the room must be increased respectively.

Reheat of the supply air when the room is overcooled has no impact on hood performance or apace pressurization. It only impacts energy cost and perhaps the distribution from outlets and the resulting airflow patterns from them. The problem associated with an insufficient supply air quantity into the room to offset heat generation in the space can, however, impact hood performance. There are essentially two schemes for accommodating a response to an increased space heating load, either (1) provide a room exhaust/supply control loop that is separate from the hood exhaust control system, or (2) increase the exhaust flow rate from the room by increasing the flow rate through the hood(s), which allows the room supply to increase accordingly. The second type of system generally requires the addition of very little control hardware. A thermostat output signal increases the hood face velocity control set point(s). Supply flow -- depending upon room control schemes -- also increases, until the thermostat is satisfied. This scheme has the disadvantage that hood face velocity and the velocity under the foiled slot open in a hood increase slightly with a decrease in hood exhaust flow rate. However, if properly applied, face velocity control has been found to have little impact on a hood's satisfactory performance. This factor has been previously documented (Anderson et al. l981) and the face velocity increase with decreasing sash opening typically ranges from 0 to +20% of open hood sash face velocity set point.

By providing an additional room exhaust/supply control loop that is independent of all hoods, the thermostat can modulate an exhaust box, the supply box is made to track one-on-one with the exhaust box, and the temperature control loop has no effect on hood operation. However, this configuration requires, as a minimum, a separate exhaust box from the room that is controlled by the space thermostat. Depending on laboratory supply control -- *space pressurization* or *flow synchronization* -- an additional supply box may be required (i.e., for *flow synchronization*).

In most instances, room conditioned supply air requirements necessary to offset space sensible heat gain rarely exceed 1 cfm/ft or approximately six air changes per hour (dependent upon actual room volume) (Rudoy 1979, p. A1.8). Supply air requirements associated with a 860 cfm hood in an 11' x 33' module, at full flow conditions and assuming a 200 cfm differential between a supply and exhaust box pair, is 1.8 cfm/ft or approximately 10.5 air changes per hour. If the same hood is in its "closed" position and flow is controlled by a face velocity control scheme, the required supply air quantity is 100 to 200 cfm or 0.27 to 0.550 cfm/ft At these minimum supply airflow rates, 1.5 to 3.3 air changes per hour are induced into the room. Velocities through the hood's foil with hood sashes closed would be approximately 75-100 fpm at 100 to 200 cfm exhaust. If the space thermostat increased the hood exhaust flow, the velocities through the slot would approximate 300 fpm at 1.0 cfm/ft^2 at 6 air changes per hour and 600 fpm at 2.0 cfm/ft^2 at 12 air changes per hour. The addition of more hoods into a one-module (33' x 11') space would, given the same scenario, reduce the velocities under the various hood slots. Air change rates in a typical E bench- type hood with multiple segmented horizontal sliding sashes would typically be from a minimum of 120 to 300 air changes per hour.

POSITIVE SPACES

Consider next the application of these same two basic control concepts applied to a "positive space." The positive space chosen corresponds to a "low" class (class 10<) electronics clean room, wherein elimination of airborne particles into the space from surrounding corridors or process spaces via migration of air into the space is to be eliminated. In this situation, the control objective is to maintain sufficient exfiltration (cfm) from the process area under all circumstances such that an average velocity across fully opened doorways is always in excess of some minimum velocity. This problem can be considerably more complex if fume hoods or similar exhaust systems must operate within the clean space.

Room Supply and Controlling Aspects. In this situation, room supply is determined by special velocity and flow patterns. It generally needs to be maintained constant at two levels: a "high flow" level, which is needed during process operations, and a "low flow" level, which is needed to ensure that infiltration into the space does not occur when process operations are not occurring. Again, if fume hoods or similar exhaust systems within the process area can be cycled on or off when the room is in its "process operation" mode, the solution to the control and contamination containment problem must involve more control loops or perhaps a mixture of types of control Systems. Supply flow in this situation is the dominant and controlling consideration.

System Control -- the Exhaust Aspect. If exfiltration from the process space is to always be ensured, especially some minimum exfiltration flow (cfm) is required, the space exhaust flow rate must be maintained at a lower volumetric flow rate than that being supplied. In this case, the minimum differential flow between supply and exhaust should be set equal to the flow corresponding to a minimum desired uniform velocity across an egress passageway opening when such passageway is at its maximum opening. Again, application of the two basic control concepts to the process area offers both significant differences and benefits to a user. Contrasting major differences are summarized and compared in Table V, which also identifies some system constraints.

Space Temperature and Relative Humidity Constraints. In some instances space temperature and relative humidity constraints are almost as critical as special velocity constraints. Fortunately, because of the large volume of air normally being circulated, these problems are much more manageable than those normally associated with zone pressurization. In most instances where the air to a space is being recalculated, reheat of the supply air is only required to offset subcooling that occurs because of humidification control constraints.

Reheating is normally done in large spaces via some "slip stream" mechanism, where only a portion of the air is treated and then blended back into the supply airflow. Aside from problems that occur with stratification and mixing when this occurs, this is a reasonably straightforward problem to deal with. Humidification or dehumidification of the supply air can also be accomplished via this mechanism. The problem becomes more difficult as the zone becomes smaller, the supply airflow is reduced, and one attempts to control the space temperature and relative humidity only with cascading controls applied to single devices -- coils and humidifiers -- that are installed in series in the supply airflow path. In this latter situation, diligent care must be given to the matching of equipment loads to hardware capability; exact matching of turndown ratios and load vs. hardware capability become even more critical if the airflow can be reduced during nonprocess operations.

CONCLUSIONS

On the basis of work done, several conclusions can be reached as follows:

Designing for a particular room Cv factor is, at best, an art that may be beyond the control of the installing contractor. Liberal system allowances of at least 25% more air capacity should be included if one is to attempt to achieve a particular zone Cv factor.

Construction specifications must be improved if a particular zone Cv is to be specified. This is of critical concern relative to smoke and life safety applications.

If a guaranteed infiltration or exfiltration level is to be achieved in a zone or if a zone is to be "maintained air negative" or positive to an adjacent space, then the application of flow tracking to the problem is probably the better system choice.

If a guaranteed pressure level is to be maintained, especially if the set point pressure level exceeds something on the order of 0.1 in WC, then differential pressurization control is the control system choice. This type of control system, because of the fewer components required for construction of a system of control loops is probably the lower cost system of the two discussed.

Systems that Incorporate both types of control loops (i.e., a pressure control loop that resets the flow associated with a supply or exhaust box in a flow synchronization loop, which was not discussed), offer some distinct advantages relative to either individual system. Response time with a combination system can always be expected to increase, however.

SUGGESTIONS FOR FUTURE RESEARCH

Extensive field testing, adjusting, and balancing efforts, which have normally followed full- scale mockup application efforts as conducted by several groups have identified several areas of needed applications research. These are briefly discussed as follows

Tuning of Control Loops

While this problem has been addressed and partially dealt with in laboratories and limited field situations, it represents a major hurdle to successful control application, especially in field situations. Within this firm, cart-mounted stand- alone computer systems have been used as adaptive control tuning systems for some time, both in mockups and in field situations. Tools (hardware and software) necessary to accomplish this type of tuning are expensive and generally unavailable to most application situations. Reduced costs associated with desktop PCs and hardware interfaces offer significant future opportunities to overcome this problem.

Statistical Assessment of Uncertainty of Measurement

This topic has also been partially dealt with by members of our firm in the application context discussed above. However, quantification of uncertainty of measurement (sensor, transmitter, etc.) and the practice and procedure

of error calculation have not been adequately treated. This information needs to be developed as tools for quantifying control and application system design constraints.
Application Research Dealing with Specific Situations

When standards dictate that spaces must be maintained "air negative" (or positive) relative to adjacent spaces, this suggests that a quantitative definition of minimum infiltration requirements has not been established in different situational applications. The terminology used in many standards, while it recognizes the problem, skirts the information needed for a meaningful solution.

BIBLIOGRAPHY

Anderson, S.A. and Waters, W.C. 1981. "A special study report of variable exhaust fume hood flow with thermostat reset." Internal report.

Butcher, E.G., and Parnell, A.C. 1979. Smoke control in fire safety design. Great Britain: William Clowes & Sons Ltd., Beccles and London.

Klote, John, and Fothergill, John, Jr. 1953 Design of smoke control systems for buildings. Atlanta: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

NFPA 45. 1975. Fire-protection for laboratories using chemicals. Section 6-3.1.3 and Appendix AE-3.1.3, pp. 45-31 through 45-32. Boston: National Fire Protection Association.

Rudoy, William. .1979. "Cooling and heating load calculation manual." Atlanta: American Society of Heating, Refrigerating, and Air Conditioning engineers. Inc.

TABLE I
MOCK-UP TEST #1
Room-to-Hall
Differential Pressure Control
(Test Series A - Room No. 1 Same Set Point, But at Different Flows)

(1) Net Hood Exhaust (CFM)	(2) Supply Flow (CFM)	(3) Infiltration (CFM)	(4) To Hall Diff. Pres. (in. W.C.)	(5) Room CV (3)/(4)
2156	1492	664	-0.0312	3759
471	230	241	-0.0049	3442
1483	1109	374	-0.0175	2827
1010	740	270	-0.0120	2464
2087	1505	582	-0.0220	3924 Hi
				(+758 +24% of mean)
1045	690	335	-0.0110	3384
2147	1530	617	-0.0300	3562
1504	1201	303	-0.0150	2473
1493	1144	349	-0.0120	3186
466	256	210	-0.0090	2213 Low
				(-953 -30% of mean)
2147	1501	646	-0.0400	3230
2146	1517	629	-0.0280	3759
2138	1504	634	-0.0346	3408
473	193	280	-0.0080	3130
1416	1138	278	-0.0110	2650
1473	1083	390	-0.0120	3250
				Mean 3166 ± 86.4

RETURN

TABLE II
MOCK-UP TEST #2A
Flow Tracking
Manufacturer No. 1

(Same Differential Flow Set Point But at Different Flows)

(1) Net Hood Exhaust (CFM)	(2) Supply Flow (CFM)	(3) Infiltration (CFM)	(4) To Hall Diff. Pres. (in. W.C.)	(5) Room CV (3)/(4)
2447	2026	421	-0.059	1733.23
2358	1962	406	-0.060	1657.49
2485	1977	508	-0.065	1992.54 HI (+286.3 +17% of mean)
2098	1740	358	-0.067	1383.07 Low (-323.2 -19% of mean)
2117	1730	387	-0.065	1517.94
2424	1933	491	-0.063	1956.19
				Mean 1706.74 ± 273.255

RETURN

TABLE III
MOCK-UP TEST #2B
Flow Tracking
Manufacturer No. 2
(Same Differential Flow Set Point But at Different Flows)

(1) Net Hood Exhaust (CFM)	(2) Supply Flow (CFM)	(3) Infiltration (CFM)	(4) To Hall Diff. Pres. (in. W.C.)	(5) Room CV (3)/(4)
2156	1971	185	-0.015	1510.52
1907	1803	104	-0.017	787.64
1778	1705	73	-0.018	544.11 Low (-1185 -69% of mean)
2207	1943	264	-0.016	2087.10
2233	1847	386	-0.025	2441.28
2053	1924	129	-0.009	1359.78
2025	1910	115	-0.012	1049.80
2293	2023	270	-0.012	2464.75 Hi (+715.48 +41% of mean)
				Mean 1530.62 ± 998.62

RETURN

TABLE IV
COMPARISON OF ROOM SUPPLY SIDE SYSTEM TYPES
(Assumes room is negative to corridor way - Typical situation is wet chemistry laboratory)

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
1. Containment of materials in fume hoods located adjacent to door when hood sashes are open.	Can present a problem if infiltration level into a room with door open is less than approximately 50-60 fpm.	Can present a major problem; Room supply boxes go to closed position when room doors are open and infiltration rate equals hood exhaust rate; flow into room tangential to hood opening and materials can be swept out of the hood.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
2. Containment of materials (e.g., spilled liquids, vapors, etc.) within the room with doors open.	Dependent on differential flows between supply & exhaust boxes and ability of control loop to maintain this	Dependent on timed response of circuit and differential pressure set point (room-to-hall differential

	differential flow into the space (i.e., infiltration). Fixed differential is best. Proportional differences in worse; problems may exist at low flown.	pressure is controlling variable and supply flow is modulated to achieve this differential pressure).
	Suggested minimum set point differential flows should be ≈ 200 cfm more for exhaust than that of a paired supply box.	Set point should be 0.01 WC; assumes hood exhaust flow control loop is independent of supply flow loop.

EXAMPLE:

With 3068 door (36" x 80") 20 sq.ft./ea. 0.01"VP = 400 fpm; 20 sq.ft. "open door" flow is 8000 cfm @ 0.01"VP, room-to-hall
With 1/4" crack under door (36" N 1/4") 0.0625 sq.ft. under each door
With four doors in laboratory

	FLOW TRACKING		**DIFFERENTIAL PRESSURIZATION**	
	One Hood	**Four Hoods**	**One Hood**	**Four Hoods**
With One Door Open	(200 cfm) 10 fpm	(800 cfm) 40 fpm	(37.5 fpm) 750 cfm	(150 fpm) 3000 cfm
With All Doors Closed	(200 cfm) 800 fpm	(800 cfm) 3200 fpm	(400 fpm) 100 cfm	(400 fpm) 100 cfm

	CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
3.	Supply spill box & supply fan effects on hallway system.	Minimal	Dynamics are a problem. Much more difficult on fan tracking, especially with more hoods in a room; more independent rooms (hoods) on a system tend to minimize this problem.

	CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
4.	Ability to operate with several doors left open.	Yes	Not recommended; comfort conditions are lost because no Supply flow exists into laboratory'.

	CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
5.	Flexibility to accommodate room airflow changes.	Depends on how supply & exhaust systems are set up; will likely require installation of supply/ exhaust box pairs. Typical turn down ratio is 3.4:1; 5:1 is possible.	If supply box is adequate mum & minimum flown), no t-up or balance effort required. Sup-ply box capability depends upon modulating range and capacity of supply box that normally will not exceed 5:1 without additional hardware coat.

	CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
6.	Control and Balance Setup.	Supply side setup can range from simple to very complex; depends on manufacturer's hardware, (i.e., digital vs. analog electronics vs. analog pneumatics).	Supply Side setup generally very simple; roan must be relatively airtight if system in to work at specified pressure level.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
7. Ability to hold fixed pressurization at various exhaust flow rates.	Fired offset: pressurization level maintained constant at all operating levels. Percentage offset: Level of pressurization varies with exhaust flow. Minimum level occurs with minimum flow.	Maintained if lab doors closed and roan is tight.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
8. Sensor locations.	A sensor is required in both supply and exhaust ductwork.	Sensor is in roan environment; additional sensors must exist in exhaust duct if flow limits (box high or low) are to be established.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
9. Measure and control of primary properties.	Measures velocity pressures; responds to induced velocity pressure and to the sensitivity of transmitter and controller.	Measures roan to hall differential pressure as function of velocity of air into roan through sensor.

RETURN

TABLE V
COMPARISON OF ROOM SUPPLY SIDE SYSTEM TYPES
(Assumes room is positive to corridor way - Typical situation in electronic clean room)

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
1. Room exfiltration	Exfiltration always guaranteed from process area if exhaust flow level with doors open yields average velocities across opening in excess of some minimum velocity. Must guard against over pressurization of space, however this can be eliminated with installation of flapper-type back draft dampers across process walls or doors to surrounding spaces.	Can present a problem if exhaust control loop response is not properly tuned; momentary infiltration can occur. Better system is to bare pressurization control loops override to reset flow synchronization levels; make flow synchronization system incorporate minimum supply exhaust flow set points.
	Dependent on differential flows between supply & exhaust boxes and ability of control loop to maintain this differential flow into the space, minimum exfiltration level is always guaranteed exfiltration). Fixed differential type control is best. Proportional difference is worse; problems may exist at low flows with this type of system.	Dependent on response of controller and differential pressure at controller set point (room-to-hall differential pressure is controlling variable and flow is modulated to achieve this differential pressure).

	Set point differential flows should be » 1000 cfm more exhaust than that of paired supply box (see basis below).	Set point should be » 0.001 WC; assumes hood exhaust flow control loop is independent of supply flow loop (see basis below).

EXAMPLE:

With 3068 door (36" x 80") 20 sq.ft./ea. 0.01"VP = 50 fpm; @ 20 sq.ft. "open door" flow is 1000 cfm 0.000157" WC up
With 1/4" crack under door (36" N 1/4") 0.0625 sq.ft. under each door
With four doors in laboratory

	---------- THEORETICAL VALUES ----------	
One Door Room	**FLOW TRACKING VP=0.000157"W.C. @ 50 fpm**	**DIFFERENTIAL PRESSURIZATION VP=0.001"W.C. @ 125 fpm**
Through Open Door	(1000 cfm) 50 fpm	(2500 cfm) 125 fpm
Under Closed Door	(1000 cfm) 16000 fpm	(7.81 cfm) 125 fpm

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
2. Ability to maintain established vertical flow pattern.	Minimal if numerous relief dampers allow for spillage with doors closed. Otherwise location of doors is critical, especially with regard to Process elements in roan. Ideal location for spill dampers is below process working floor.	Minimal if only a mall box responds to pressurization controller and major portion of airflow is established via flow tracking. Otherwise, much more difficult with this type system; works well only in large space.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
3. Ability to hold fixed exfiltration level.	Fixed offset: level is constant and always maintained. Percentage offset: level varies with exhaust flow setpoint; minimum differential flow occurs at minimum flow.	Varies with opening & closing of lab doors; minimum flow depends upon how tight roan is and wall penetrations.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
4. Flexibility to accommodate roan airflow changes.	Excellent, depends on how supply & exhaust systems are set up; might require installation of additional special supply/exhaust box pairs.	If exhaust box is adequate (maximum & minimum flows), no set-up or balance effort required. Exhaust box capability depends upon modulating range and capacity of exhaust box and box controller.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
5. Ability to operate with doors left open.	Yes. May impact vertical air-flow pattern.	Yes. May impact vertical airflow pattern.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
6. Control and Balance Setup.	Exhaust side setup, typically very simple, depends on number of box pairs to be set up and how the pairs are staged. Bard- ware sets can	Exhaust side setup generally very simple; room must be airtight if system is to work at a specified pressure level; exfiltration level at particular

	range from simple to very complex; depends on manufacturer's hardware (digital or analog electronic or analog pneumatic).	set point is not guaranteed.

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
7. "Pickup" exhaust box and exhaust fan effects on hallway or non-process area return system.	Minimal system impact.	Control Dynamics are a problem. Much more difficult on fan tracking system. Better system performance is gained with increased number of independent subsystems served (i.e., more rooms or more independent boxes in a room).

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
8. Sensor locations.	A sensor(s) is required in both the supply and exhaust ductwork.	Sensor is in room environment; additional sensors must exist in exhaust duct if flow limits (box high or low) are to be established. Great care needs to be * exercised with sensor choice to insure controller responds only to flow in one direction through it (i.e., ability to discriminate exfiltration vs. infiltration).

CONSIDERATION	FLOW TRACKING	SPACE PRESSURIZATION
9. Measure and control of primary properties.	Measures velocity pressures; responds to induced velocity pressure and to the sensitivity of controller.	Measures room to hall differential pressure as function of velocity of air into room through sensor.

RETURN