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IMPORTANCE OF FLOW TRANSMITTER SELECTION FOR RETURN FAN CONTROL IN VAV SYSTEMS

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ABSTRACT

The approach to both outside air and building pressurization control in large buildings requires understanding the function of the return/exhaust fan. The function of the return/exhaust fan is to return system air to the supply fan at a known rate and to provide exhaust of excessive outside air during special operating conditions and in extreme emergencies to provide the system with partial air capacity in the event the supply fan fails. The return/exhaust fan is the key to outside air and building pressurization control. The flow transmitter is one of the keys to accurate return/exhaust fan control. This paper deals with the selection and application of the flow transmitter as it applies to outside air and building pressurization control. The control strategies fall into one of two categories: open-loop control or closed-loop control.

INTRODUCTION

Variable-air-volume (VAV) systems are commonly installed in new commercial, industrial, and institutional buildings. The primary reason for the popularity of VAV systems is their energy efficiency.

In order to achieve the energy-efficiency level expected of the VAV system, two areas of high energy use must be precisely controlled—fan horsepower and tempering of outside air. Approximately 30% of a large building's electrical energy load is consumed by the air-conditioning fans. With this large electrical energy load concentrated at one point, fan control schemes should be given a good deal of consideration.

Control of outside air should also be given a good deal of consideration in order to eliminate excess outside air tempering caused by inadequate controls and/or excessive infiltration caused by high negative building pressure.

The approach to both outside air and building pressurization control in large buildings requires understanding the function of the return/exhaust fan. The function of the return/exhaust fan is to return system air to the supply fan at a known rate and to provide exhaust of excessive outside air during special operating conditions.

This paper evaluates the various control strategies of outside air and building pressurization. The control strategies fall into one of two categories: open-loop control or closed-loop control.

An open-loop airflow control system does not have a direct link between the value of the controlled variable and the controller. Without a direct link to the controlled variable, numerous extraneous forces tend to influence the control signal in both its dynamic response rate and its ability to provide an accurate control signal.

A closed-loop airflow control system measures the actual changes in the controlled variable and activates the control device to bring about a change. This corrective action is continuous until the variable is brought to setpoint. This system of transmitting the value of the controlled variable back to the controller is also known as feedback.

SUPPLY FAN CONTROL

In modern VAV systems, closed-loop control of the supply fan as a function of system static pressure is typically accomplished by using a static pressure sensor located toward the terminus of the air supply system, usually about two-thirds of the distance into the system or at a representative location at which monitoring is preferred. Commercially available static pressure sensors provide an output signal that is then processed into an electronic or pneumatic signal which is proportional to the static pressure sensed. The signal proportional to pressure is then used to control the volume of the supply fan so as to maintain the static system pressure reasonably constant despite changes in system demand.

RETURN/EXHAUST FAN CONTROL

1. The building's static control senses the differential pressure between a typical room and the outdoors and increases the volume of air handled by the return/exhaust fan as the building pressure increases. The difficulty of determining a typical room in a large system and of

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obtaining a stable outdoor reference are disadvantages of this control method, which also does not control outside air as a function of delta cfm between the supply flow rate and the return flow rate. This open-loop control sequence is difficult to calibrate and tune for full-range control.

2. This control sequence provides the return/exhaust fan with the same signal as the supply fan, which is being controlled by system static pressure. This open-loop method provides a delta cfm at one point of operation, full volume only. Whenever the system airflow volume is reduced, which is the majority of the time, the return/exhaust fan will not provide controlled building pressurization. Outside air and building pressurization are also out of control the majority of time.

3. This control sequence provides the return/exhaust fan with a signal that is derived by comparing the supply fan flow rate to the return/exhaust fan flow rate. This closed-loop method provides volumetric synchronization with system-designed delta cfm throughout the range of system turndown. Building pressurization and outside air can be brought into adjustment to match the dynamics of the building and its occupants with this closed-loop method of return/exhaust fan control.

Because of the distinct shortcomings of methods 1 and 2, method 3 will be considered in detail as a measure of bringing outside air and building pressurization under control.

METHOD #3

For systems utilizing a return/exhaust fan, it has been typical to use flow sensors on the output of the supply fan and on the input or output of the return/exhaust fan, allowing the flow rates of the two fans to be compared, and using the comparison signal to control the return/exhaust fan volume. For example, the volumetric output of the supply and return/exhaust fans is to be controlled by utilizing motorized inlet dampers on the two fans. The supply and return/exhaust fans are controlled so that a pre-selected flow rate differential between the two fans is maintained, with the return/exhaust fan having a lower flow rate than the supply fan. The flow differential between the two fans corresponds to the flow of air exhausted from the building to satisfy code requirements. The output of the return/exhaust fan is directed back to the input of the supply fan, and the difference in flow rate between the two fans is made up by connecting an outside air duct to the input of the supply fan, thereby allowing outside air to flow into the supply fan at a rate equal to the differential between the flows through the supply fan and return/exhaust fan. The mixture of recirculated and outside air provided to the supply fan may be tempered—heated or cooled—at the input or output of the supply fan.

Within this same control arrangement lies the ability to control building pressurization. The building has a normal exhaust requirement (toilet rooms, etc.). The normal exhaust volume is more or less than the outside air volume required by code occupancy. If the normal exhaust is more, the solution to building pressurization control is met by changing the setpoint of the return fan controller to increase the delta cfm of outside air volume until it matches the building's exhaust. Thus the building is under pressurization control. If the outside air volume per code is greater than the building exhaust, increase the exhaust fan capacity until the building goes slightly negative, then trim the system with the return/exhaust fan controller.

In addition to matching outside air to normal exhaust requirements, here lies the ability to match the dynamics of the building pressurization in regard to building porosity and stack effect. During design, these values are difficult to predict with certainty. Building porosity (infiltration) may be dealt with by increasing the delta cfm while the normal exhaust is operating until the building pressure is slightly positive. This type of balance will serve for the majority of time. Some upsets will occur, caused by wind pressure and atmospheric conditions. Depending upon the severity of the upsets, the building's positive pressure may be adjusted slightly upward to achieve a more stable condition. Stack effect is similarly handled. With an equipment room, approximately every seven floors, each multi-floor zone may be handled as an independent pressure problem with the solution in the control of the delta cfm of its zone return fan. Whether or not a zone is above or below another zone or how high or low in the building, the entire building will be under pressurization control as long as the pressure relationship is maintained between the adjoining zones.

Additional individual floor supply and return synchronization using the same control loop logic and instrumentation as the return/exhaust fan loop will provide precise pressure differential control when required. Elevator lobbies and stairwells could thus be pressure controlled as dedicated zones or systems. The various modes (morning warm-up, economy, night setback) are all compatible with this type of return fan control.

INSTRUMENTATION

The return/exhaust fan is controlled with volumetric synchronization, which is also called constant-air-volume differential or delta cfm. Duct airflow rates are sensed at multiple airflow-measuring stations with total and static pressure signals sent to respective velocity pressure transmitters. These signals are sent to square root extractors, where they are made linear to velocity, and then to multipliers, where the airflow-measuring station area factor is applied to make them linear and scaled to air volume. A dual-input controller receives these signals and compares one signal with the other and, based upon a setpoint relationship between these two signals, issues a control signal to reposition a return/exhaust fan-connected volume control device to maintain constant delta cfm between the supply fan and the return/exhaust fan flow rates throughout the full range of system turndown.

DIFFERENTIAL PRESSURE VELOCITY TRANSMITTER

Of these instrumentation components, the transmitter is the most critical. The primary sensor (airflow-measuring station) is a straightforward selection placed in an obvious position in the ductwork. The airflow controller is required to have three distinct modes of control—proportional, reset (integral), and derivative (inverse). The action of the derivative mode is to permit the controller to be tuned to the dynamics of the airflow system and thereby eliminate control hunting, cycling, and instability. The square root extractor may or may not be part of the transmitter as the scaling multiplier could also be. In most cases, these two components are grouped together with the transmitter and called a flow transmitter.

Simply stated, the return fan is the key to outside air and building pressurization control and the properly selected differential pressure velocity transmitter is the key to controlling the return fan.

Selection of pneumatic differential pressure velocity transmitters requires the same consideration as the electronic transmitters. Electronic transmitter nomenclature will be used during this discussion.

The sole function of the differential pressure velocity transmitter in the airflow control process is that of amplification of the sensed flow signal into an electronic signal that can be used in an analog or digital control loop. It is the ability of the selected transmitter to perform this single function that is of concern. A transmitter cannot make these signals any better than originally sensed, but it can destroy the entire ability of the control system to perform by the distortion of those sensed flow signals.

The three principal considerations for selection of the differential pressure velocity transmitter for airflow control application are reference accuracy, operating span, and thermal effect.

Reference Accuracy

Reference accuracy represents the basic capability of an instrument and its designed ability to perform within specified criteria. Reference accuracy is, therefore, the "visible summation" of all the inaccuracies of the instrument. For transmitters, this includes nonlinearity, hysteresis, dead band, and nonrepeatability. Reference accuracy is measured and published as a percentage of the full span of the instrument. When stated, reference accuracy is actually a statement of inaccuracy; 1.0% of full span means the instrument has an inaccuracy of 1.0% at full span.

Operating (Input) Span

The operating span is that input span at which the transmitter is required to operate by the system to which it has been applied. For example, a transmitter with a designed full-span input signal of 1.0 in. w.c. may find itself applied to a control system wherein the sensed input signal from a flow measuring station is 0.12 in. w.c. This latter value represents the operating input span. The importance of this operating span, therefore, is in its relationship to the full span of the instrument and the effect on the reference accuracy that was determined by actual testing with a full-span input signal. The reference accuracy of the transmitter must be adjusted to reflect any difference between full input span and the operating input span by use of the following formulation:

$$\begin{array}{c}\text{Reference Accuracy}\\ \text{(\% of Full Span)}\end{array} \times \frac{\text{Full (Input) Span}}{\text{Operating (Input) Span}} = \begin{array}{c}\text{Instrument Accuracy at}\\ \text{Operating Input Span}\end{array}$$

Thermal (Temperature) Effect

Thermal effect is the measure of the error added to an operating instrument caused by changes in the ambient temperature of the air surrounding the instrument. This error is due to different coefficients of expansion of materials used in its construction coupled with finite fabrication tolerances, etc. We should remember that these operating inaccuracies, listed as "thermal effect," are not included in the published reference accuracy for the instrument. Thermal effect is always expressed as a "percentage of full input span." Therefore, the same corrective formulation required to calculate the reference for a given operation input span must also be applied to the published thermal effect values. In addition, both the zero and span must be treated with this thermal effect, thereby doubling the effect when added to full-span accuracy.

Thermal effect is infinitely more dramatic and critical in the application of differential-pressure velocity transmitters than in other control devices due to three factors:

1. The ultra-low magnitude of the sensed input signals with which these instruments are required to operate.

2. The resulting magnitude of the combined transmitter accuracies (reference plus thermal effect) in relation to the magnitude of the operating input signals.

3. System turndown, wherein the operating input span of the transmitter is reduced to reflect a reduction in the overall system air volume.

For example, in VAV fan control systems, turndowns of overall system operating to 25% of capacity can be experienced. While this condition represents a flow turndown of 4:1, it actually represents a 16:1 turndown in the operating input span.

When a differential pressure transmitter is required to operate under system turndown, the inaccuracy of signal error, added to the thermal effect when the transmitter is not properly temperature compensated, can be several times greater than the magnitude of the operating input signal itself.

For example, a differential-pressure velocity transmitter with an accuracy of 0.5% FS, a span of 0 to 1.0 in. w.c., a thermal effect of 0.05% FS/F, and operating at 1000 fpm in a machinery room that has a 20°F temperature shift will result in an accuracy of ±24%. Because each of the two flow transmitters (supply and return) will probably have similar characteristics, it is quite conceivable that the direction and magnitude of error at one transmitter in the synchronization loop may be the opposite of the other transmitter. Therefore, when considered as a system, the errors should be added to obtain the potential system control error. The transmitter location in the space becomes a major consideration. In order to minimize and/or eliminate the signal error introduced by thermal effect, it becomes necessary to select flow transmitters with true temperature compensation or have self-calibrating features built into the flow transmitter to zero out the thermal drift.

The three basic considerations—reference accuracy, operating input span, and thermal effect—for proper selection of differential-pressure velocity transmitters are not theoretical. They represent the factors that must be considered by the design engineer in order for the control system to respond correctly.

Instrumentation for closed-loop control of the return/exhaust fan must be of industrial quality in order to achieve the maximum allowable system turndown. Industrial-quality instrumentation could be defined as instrumentation that is specified in the standard form and nomenclature of the Instrument Society of America (ISA). A guide to the overall system accuracy of the airflow controls could be written in the project specification as follows:

Full volumetric synchronization of supply and return fan within ±3% of cfm differential setpoint over the *entire range of system operation and turndown* and, further, constant air volume control within ±11/2% of air volume setpoint.

As can be seen, any individual instrument that exceeds this accuracy cannot be used to control the loop. The accuracy of the individual instrument must be measured at the lowest operating input span and the highest temperature differential the instrument will see while operating. This points out the necessity of using high-quality, accurate, low-span, temperature-compensated differential pressure velocity transmitters in the control loop. In addition to the above, these transmitters should be field span adjustable, not fixed span. There should be a range of adjustability available to be used in tuning the flow transmitter to the actual dynamics of the system.

CONCLUSION

Items deemed essential for the successful control of outside air and building pressurization within a VAV system are:

1. Good overall system design considerations.
2. The selection of a differential pressure velocity transmitter.
3. The use of closed-loop control strategies.
4. The precise control of return/exhaust fan.
5. The use of high-quality instrumentation.
6. A complete and definitive specification.
7. A complete ISA control loop schematic.
8. The overall system performance (accuracy) specified.
9. Submittals with instrumentation specification shown in detail.
10. Careful selection of system dampers.

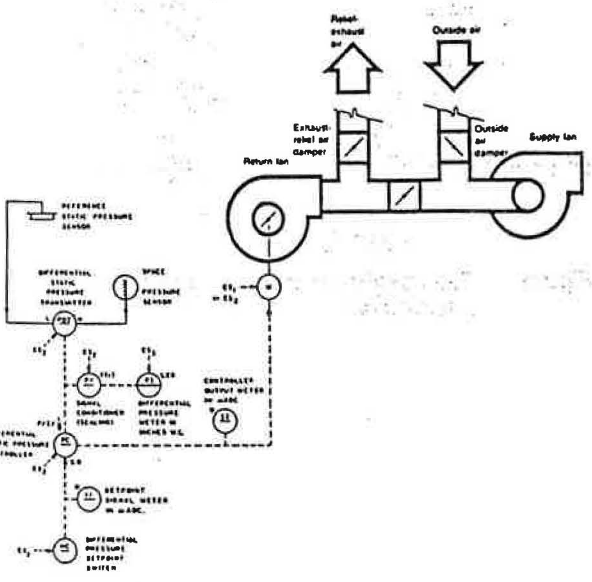

Figure 1 *A return/exhaust fan controlled by building static pressure*

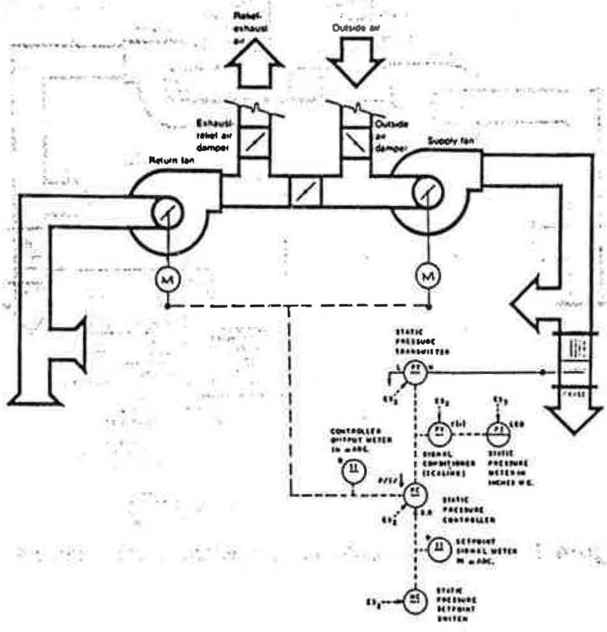

Figure 2 *B open loop return/exhaust fan controlled by system static pressure*

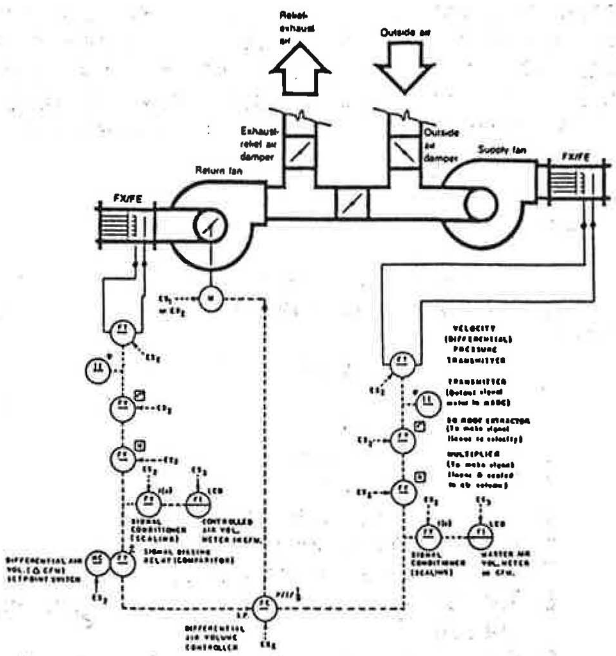

Figure 3 *C return/exhaust fan controlled by volumetric synchronization*

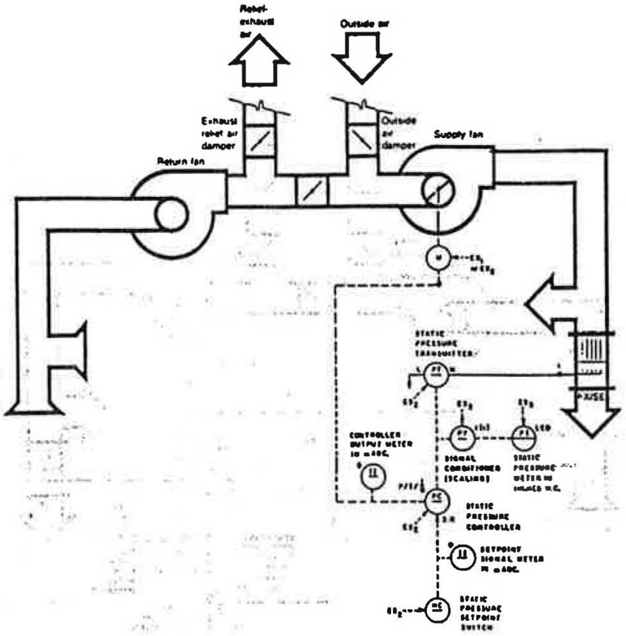

Figure 5 *Supply fan controlled by system static pressure*

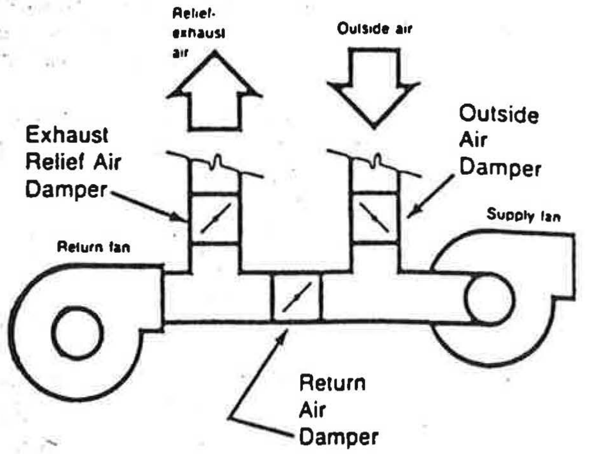

Figure 4 *System dampers*

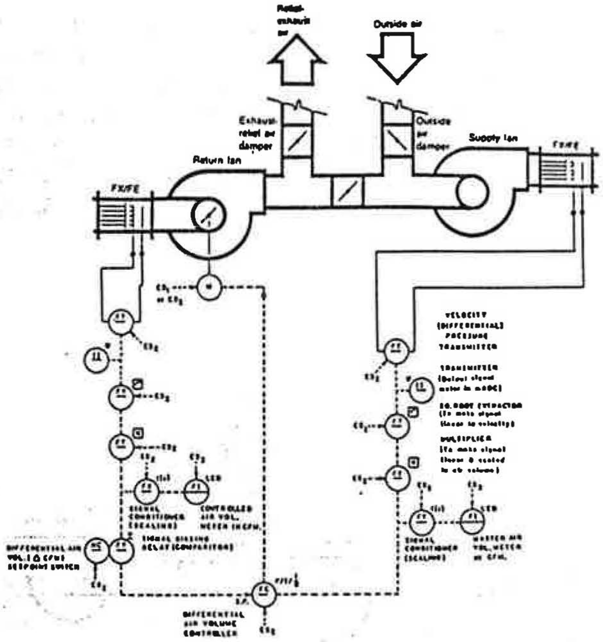

Figure 6 *Return/exhaust fan controlled by volumetric synchronization*

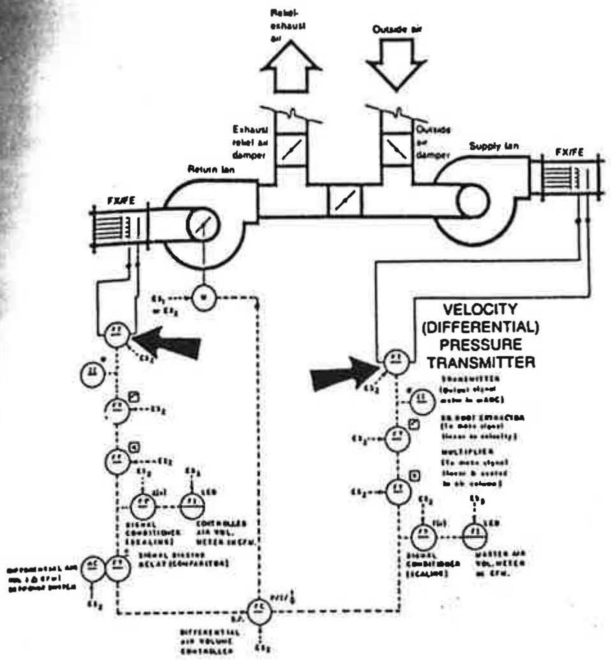

Figure 7 *Return/exhaust fan controlled by volumetric synchronization, differential pressure velocity transmitter*

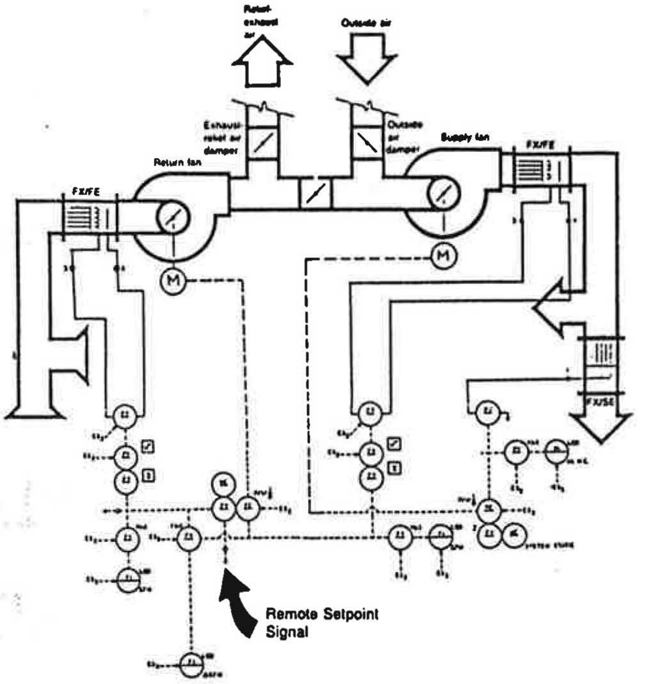

Figure 8 *System tie-in for reset of delta cfm and controlled outside air*

DISCUSSION

L.A. Damiano, Director of Sales/Marketing, EBTRON, Inc., Belle Mead, NJ: Mr. Smith has done the industry a great service in highlighting a critical variable in the selection and use of velocity pressure measurement equipment with electronic control systems. Most temperature controls contractors have little awareness of the importance to the measurement's effectiveness of transmitter selection and the effects of temperature fluctuations.

My question addresses the overall potential of system accuracy in the configuration generally referred to in the paper. Under "thermal effect," Mr. Smith states that errors should be "added" to obtain the potential system control error. I would like to know if Mr. Smith intended to reference the "root sum-of-the-squares" method.

Also, Mr. Smith referenced accuracy potentials of "±3% of cfm differential setpoint" and "±1½% of air volume setpoint." I would like to know the specifications of the equipment used to obtain these levels of "system" accuracy and the standard against which the accuracies were derived. Is the level obtained for a specific field or lab condition(s) and, if so, what are the specifics of the condition?

R.B. Smith: Answer to system accuracy: Two methods of looking at system accuracy would be as follows: (1) *Maximum deviation* directly adds the accuracies of each component in the control circuit; (2) *Probable deviation* adds the squares of the individual component accuracies and then takes the square root of the resulting sum.

Answer to specifications/instrumentation/standard condition: The specification that could be used to fulfill the mentioned setpoints is General Services Administration #PBS(PCD): 15980, July 1979 or later; the specification for individual instrumentation should be obtained from instrumentation manufacturers; the control instrument component performance could be expressed in terminology in accordance with ANSI/ISA S51.1-1979 American National Standard Process Instrumentation Terminology, and ANSE MC4.1-1975 (ISA-S26) Dynamic Response Testing of Process Controls. The accuracies could be obtained using field conditions and normal operating characteristics.