EXAMINATION OF REFERENCING SYSTEMS

With very high sensitivity detectors the problem of external pollution entering an area gets more acute. This examination indicates a serious problem associated with the use of a reference detector and shows how special features of the STRATOS® detector may be used in providing a solution.

When a room is to be protected with smoke detectors, there are two prime considerations. The first is that it *should not* give an alarm which, for any reason at all, does not correspond to a real fire situation as required by the user. The second requirement is that it *should* give an alarm for a real fire situation.

One possible source of unwanted alarms is the ingress of smoke into the protected area from an outside source. With very high sensitivity systems, such as aspirating systems, this can be a very real problem. Outside sources of smoke pollution may easily rise to levels above 10% obs/m., more than a hundred times the alarm level of a high sensitivity air sampling detector system such as Stratos™. Where such situations are likely, the system designer will frequently employ a reference detector.

A referencing system depends upon the basic equation:-

[pollution leaving the area] - [pollution entering the area] = [pollution added from within the area]

On the face of it, this seems to offer a complete solution to the problem. One detector is sited to measure the level of pollution at the air inlet to the area and another is sited to measure the pollution of the air at the outlet from the area. The difference between these two readings is used to trigger an alarm if it rises above a given alarm level. If no pollution is added from inside the area the difference between the two readings will be zero.

There are certain problems which occur in implementing the theory. The most obvious one is that, for a detector with a sensitivity of 0.1% obs/m full scale, the two measurements must track one another to within 1%. Another is that the signal from a detector does not carry on rising indefinitely, it reaches a ceiling where, in spite of increasing pollution the output signal will no longer rise. If the signal from the reference detector equals this level, the detector will not be able to rise above it. For instance, an alarm level cannot be reached when the pollution level added in the room rises.

example: reference detector at inlet can give a signal of 1 volt per 1% obs/m. with a maximum output of 10 volts.

detector at outlet can give a signal of 1 volt per 1% obs/m. with a maximum output of 10 volts.

alarm will be signalled if the difference becomes greater than 0.1 volts.

If the inlet detector senses 10% obs/m or more, its output will be 10 volts and this is the maximum it can give. The same, or more, will be detected by the detector at the outlet, but it too cannot give an output above 10 volts.

[pollution entering the area] - [pollution leaving the area] = [pollution added]

[10] - [10] = [0] regardless of pollution added within the area

Stratos™ solves this problem by ensuring the detector is always able to go into alarm using it's patented ClassiFire™ technology. However there is another problem which cannot be solved by the designer of the detector but must be solved by the system designer. This is the transient problem of the changes which occur when pollution starts to be detected at the inlet and when it ceases to be detected.

In order to examine what occurs, it is easiest to examine a simple case and then examine the effect of variations. The following examinations make 2 assumptions. The first is that a constant level of external pollution occurs. The second is that perfect mixing of incoming air occurs instantaneously. Although this will not be realised in any practical case, it will be closely approached. An area is taken which either has filtered air fed into it from outside or has air being extracted from it and air entering it where possible. Figures 1 & 2 depict such areas. The graph in Fig. 3 shows how the pollution rises at the outlet of the area with time and the graph in Fig. 4 shows how the pollution falls at the outlet of the area with time. Both show the result of the basic referencing equation assuming theoretically perfect detectors.

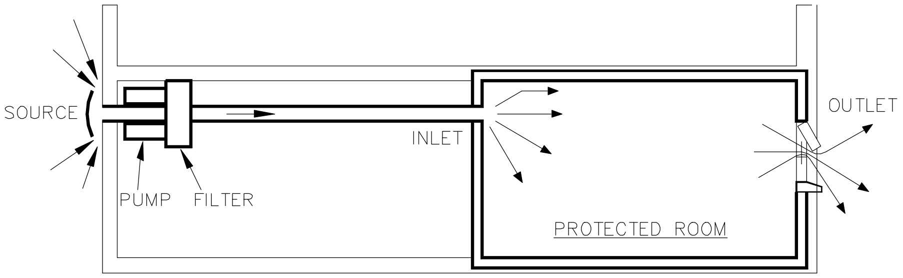

Fig. 1. Simple case of filtered air input and natural venting.

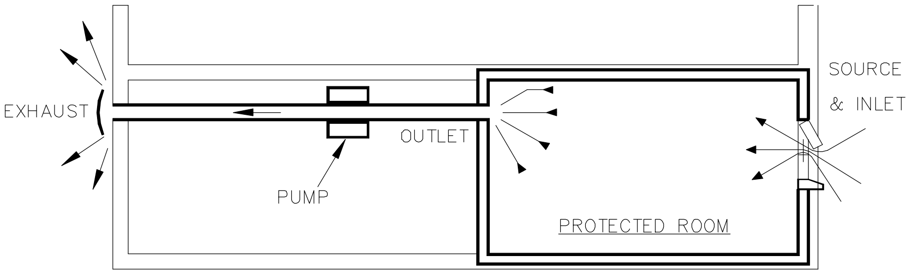

Fig. 2. Simple case of forced air venting and natural inlet of air.

At the onset of pollution at the inlet the pollution at the outlet will not immediately rise to the same level. For a pollution level of X% arriving at the inlet, the pollution level at the outlet will rise with the inverse exponential of time towards X% and in theory never actually reach it. This effect is illustrated in Figs. 3 & 4.

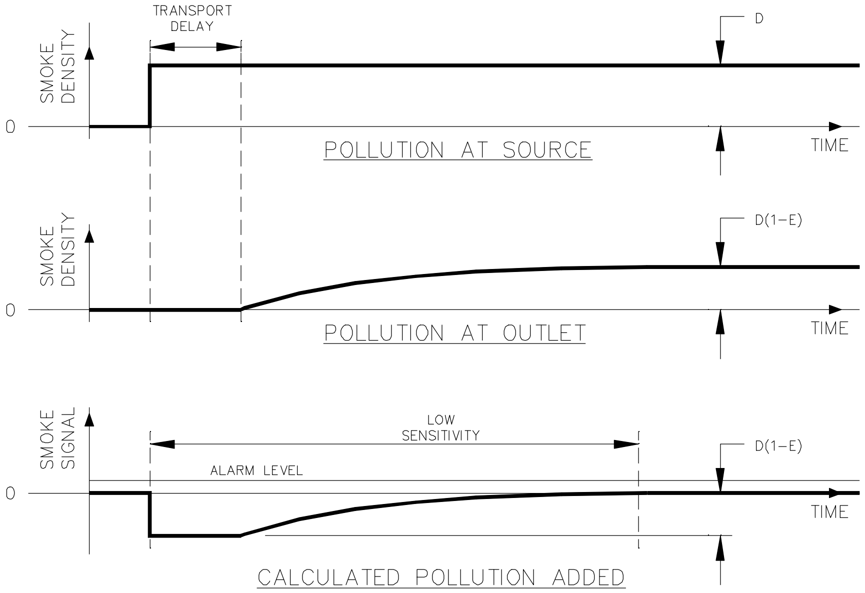

Fig. 3. Smoke levels at the onset of an external source of smoke.

The SOURCE is considered as the point where pollution from an external source enters the controllable system. In most cases this is the building in which the protected room is sited.

In Fig. 1. there is some distance between the source and the room. There is thus a delay in air reaching the room corresponding to the time taken for air to travel the distance. The graphs in Figs. 3. & 4. label this as TRANSPORT DELAY. For Fig. 2. there is no distance between the SOURCE and the protected room, therefore the TRANSPORT DELAY is zero. It is important to note that this situation is not inherent in the forced air ventilation case because the INLET may be from another part of the same controllable system.

The INLET is the point where air enters the protected room. For the sake of simplicity, this is considered to be a single point but in practice this is not necessarily the case.

The OUTLET is the point where air leaves the protected room. Again, for the sake of simplicity, this is considered to be a single point but in practice this is not necessarily the case.

Filtering indicated in Fig. 1. may have an effect in reducing the amount of pollution in the incoming air. Its efficiency is shown as E in Figs. 3 & 4. If it is 100% efficient then $E = 1$ and there is no apparent need for referencing.

The rate of change of pollution at the OUTLET is shown to be inversely exponential. The assumption is that polluted air entering the room is instantly mixed with the existing air in the room. Since air is entering the room air must also be leaving the room and a proportion of this air must be polluted air. The proportion of polluted air leaving will increase as its proportion in the room increases. This is a classic case indicating an inverse exponential increase. If air is not perfectly mixed and is not mixed at all, a "wave front" of polluted air will advance across the room and the pollution at the OUTLET will suddenly rise when the wave front reaches it. This will correspond to a delay which is the time taken for the "wave front" to traverse the room. This is an unlikely state of affairs. If the mixing is short of being perfect but exists, then the rise will be similar to that shown but not follow an exact inverse exponential path. Assuming perfect mixing is fairly close to what can be expected in practice and allows a mathematical analysis of the situation.

It will be noted from Fig. 3 that there is a period for the CALCULATED POLLUTION ADDED when the detector is in a state of low sensitivity. This is one of the major errors the system designer is trying to avoid by using a reference system. The exact duration of this period and the extent of the low sensitivity will be assessed later from a mathematical analysis.

In Fig. 4 the same items are illustrated as in Fig. 3. but which correspond to the time when the external source of pollution ceases.

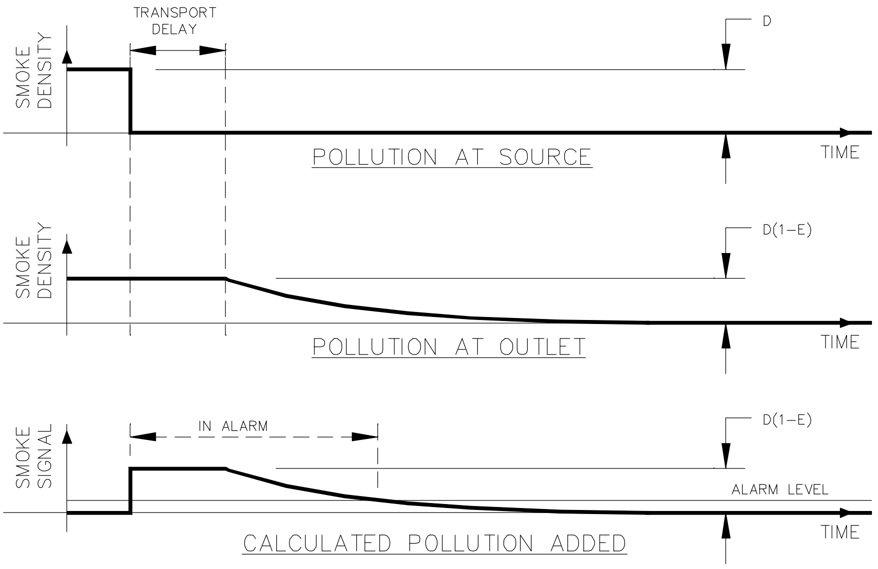

Fig. 4. Smoke levels at the end of an external source of smoke.

It is a common error made by many people, that the time scale for pollution increasing in a room is different from that of pollution decreasing. This is not true but may be subjectively enforced due to the more rapid change seen at the start of inverse exponential function. Exactly the same mechanism is working in both increasing and decreasing pollution. The only difference is that in one the added air is polluted and in the other the added air is clean. As can be seen from Fig. 4. there is a period immediately following the end of the input of pollution when the detector is in alarm. This is exactly what the system designer is trying to avoid by using a reference system.

For the case when pollution is increasing in the room:-

$Cr = Cs\ 2\ (1 - \hat{}\ ^{-t / T})$

where T is determined by the volume of the room and the rate at which air is introduced:

$T = V/R$ (mins)

For the case when pollution is decreasing in the room:-

$Cr = Cs\ 2\ \hat{}\ ^{-t/T}$

For the transport delay time:

t*d* = L / (A 2 R)

Cs = pollution at the source.
Cr = pollution in the room.
t = elapsed time.
T = time constant
R = rate of air introduction (cu.m./min.)
V = volume of room (cu.m.)
E = efficiency of filter.
A = X-sect. area of duct (sq.m.)
L = length of duct. (m.)
t*d* = transport delay time. (mins)

Example:

A room has a volume of 5,000 cu.m. and the air conditioning is such that it provides 5 changes of air per hour and the fresh air make-up is 10%. Air enters the building via an air filter which is 30% efficient at removing pollution and travels 25 metres down an air duct (2m² area) to the room. A reference detector is placed after the air filter to provide reference for a standard detector which samples air leaving the room. The detector will indicate an alarm if pollution rises to 0.1% obs/m.

If a diesel lorry draws up outside and emits a pollution level of 5% obs/m at the reference detector; what is the period for which the detector will alarm at more than 0.2% obs/m and how long will it remain in an alarm condition when the lorry moves away.

5 changes per hour = 5 x 5000 cu.m. per hour
= 416 cu.m per minute
10% make up = 41.6 cu.m. per minute
Transport delay in 2 sq.m. duct = L / (A 2 R)
= 25 / (41.6 x 2)
= 0.30 minutes
Effective pollution = (1 - E) 2 [absolute pollution]
= (1 - 0.3) x 5 % obs/m
= 3.5 % obs/m

The alarm will be activated by 0.2% added pollution when the pollution at the outlet has risen to (3.5 - 0.1) % obs/m = 3.4 % obs/m. This allows for 0.1% added to reach the alarm level and 0.1% to overcome the residual reference signal. The time taken for the pollution level at the outlet to rise is "t" in the equation:

Cr = Cs 2 (1 - ^ $^{-t/T}$) where Cr = 3.4%
Cs = 3.5%
T = V / R = 5000/41.6
= 120 mins.

transposing

t = T 2 ln(Cs / (Cr - Cs))
= 120 x ln(3.5 / 0.1)
= 427 mins

The alarm will be activated until the pollution at the output has fallen from 3.5% obs/m to 0.1% obs/m. It is given as "t" in the equation:

Cr = Cs 2 ^ $^{-t/T}$ where Cr = 0.1%
Cs = 3.5%
T = 120 mins.

transposing:

t = T 2 ln(Cs / Cr)
= 427 mins as before

These figures must have added to them the transport time (which is insignificant compared to them) and they illustrate, very clearly, a very large problem. It can be argued that a step change in the external pollution will never occur and represents the worst case. This is true, but, specifying that the pollution at the source will take 1 minute to rise to 5% will not provide significant improvement on the figures calculated above. A possible solution is to increase the effectiveness of the filter. If the filter is made 90% efficient then Cs becomes 0.5% in the above equations and:-

$t = T\,2 \ln(Cs / Cr)$

$= 193$ mins

If the filter could be made better than 98% efficient then the detector would approach alarm and, although it would not be sent into alarm, it *would* become hyper sensitive to any smoke added in the room. Added to this, if the filter is this efficient, then it could arguably be improved to remove nearly all pollution from an outside source. In this case no reference system would be required to compensate for it.

The main factor in the determination of time in alarm or time in low sensitivity is the time constant "T". This, as given above, is the volume of the room divided by the rate at which outside air is added. That is the time it would take a room to be filled with external polluted air if none of the pollution was allowed to escape. For this reason it is called the filling time constant. If the example worked through above, was concerned with a room of 500 cu.m. but all other data remained the same, then the filling time constant (T) would be 12 minutes instead of 120 minutes. The alarm level would be exceeded for 42.7 minutes instead of 427 minutes. The same would be true if the rate of fresh air make up was 100% instead of 10% and the volume of the room stayed at 5,000 cu.m. However, shortening the period in unwanted alarms by this amount is not a real solution because 1 second in alarm constitutes as much of a problem as 42.7 minutes.

It has been shown that in a simple case the performance of a reference system can be analysed by "rounding off a few corners". The main problem has been identified as the filling time constant.

When considering a more complex system as in Fig. 5 the number of unknown variables become so many and so large that the system is no longer amenable to analysis.

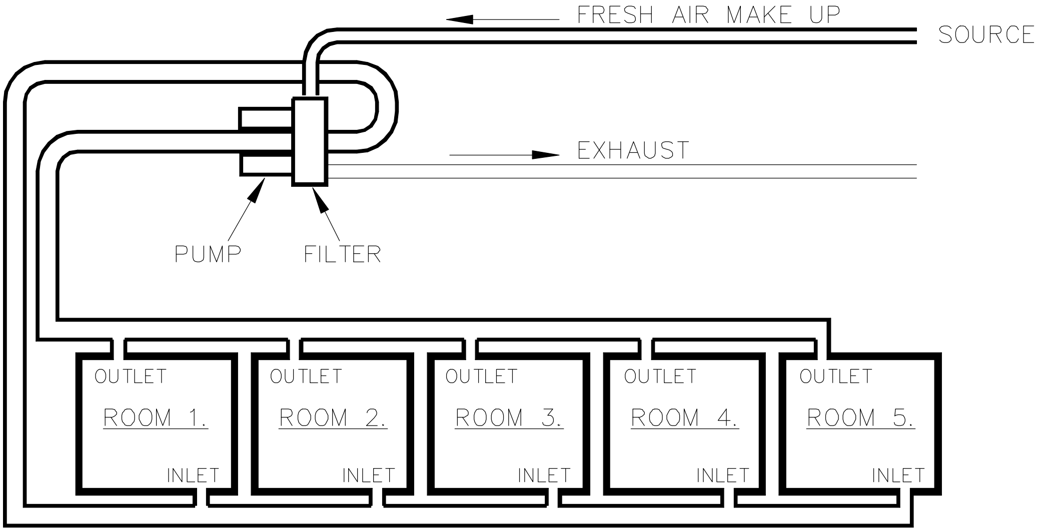

Fig. 5. Complex situation with more than one room serviced by a single air conditioning unit.

The ability to vary the air conditioning in one of the rooms can effect the flow into all the rooms. Air ducts will become long with the result that transport delays will vary and be significant. Some rooms may have the ability to turn off their air conditioning completely and rely on the opening of windows. Referencing under these conditions will only provide a false sense of security. Unwanted alarms may easily occur from one of the rooms as a result of a change in conditions in another room. Such causes are very difficult to trace. The only solution in this instance is to have individual referencing in each room and the ability to turn it off when it is not required. With individual referencing a reference detector will be sited at the inlet to a room and will reference a detector at the outlet. Problems can still occur due to the change of flow rates, but the requirements for a particular room can be analysed and errors can be identified as originating from a given room.

Stratos detector

Because of the difficulties associated with complex systems, the Stratos detector does not cater for transport delays or rooms with a very long time constant. The general advice to system designers is to keep a reference system as simple as possible because of the inherent pitfalls.

Stratos does contain a solution for the filling time constant which is available separately programmable for each detector in a system. The variations of smoke density and signals associated with this are shown in Fig. 6. The intent is to modify the reference signal such that:-

[modified sig. representing] [signal representing] [signal representing]
[pollution entering the area] - [pollution leaving the area] = [pollution added from]
[within the area.]

This can be identified as a modification of the original basic equation.

There are two variables which can be programmed into the Stratos which modify the reference signal to suit it to the situation of the detector. The first is the filling time constant and the second is the attenuation. The effect of these on the reference signal is illustrated in the curve "MODIFIED REFERENCE SIGNAL" in Fig. 6. The filling time constant entry is labelled as "Reference back off time delay (mins)" in function 8. This should be set to be equal to the filling time constant and has a maximum value of 99. It will modify the reference signal for the one detector concerned by providing an inverse exponential rise and fall to the reference signal. The second programmable variable is "Reference level" at function 7. This should be set to be equal to (1 - E) where E is the efficiency of a relevant filter as defined above. It is the factor "K" shown in the curve "MODIFIED REFERENCE SIGNAL" in Fig. 6. The purpose of these two programmable variables is to match the effect of external reference to the response to external pollution of the detector at the outlet. Perfect matching will only be achieved if there is very good mixing in the room resulting in an inverse exponential change of pollution within the room, as previously explained. Providing that the external pollution level is not exorbitantly high, some trial and error adjustments around the setting of the "Reference back off time delay (mins)" in function 8 will achieve good results. Very good matching can be obtained under most normal conditions and will be a very great improvement on using an unmodified reference signal.