Ventilation Failure Alarm : 2 case studies

Summary

Ventilation failure alarms are typically based on an over temperature trigger point. Temperature data on prolonged ventilation failure is sparse since monitored incidents are rare. This paper studies two incidents of prolonged ventilation failure affecting a group of 8 farrowing rooms and a large dry sow building. It illustrates the resulting temperatures and questions the efficacy of over temperature alarm as typically implemented and operated.

In the cases studied, rates of temperature rise fell from an initial value around 0.1°C per minute to 0.01°C per minute within 2 hours.

Background

Most intensively reared pigs in the UK and other developed countries are housed in buildings with automatic or partly automatic ventilation.

Pigs produce heat - around 2W per kg body mass, along with CO^2 and humidity, and toxic gases are produced from slurry. Ventilation is intended to remove heat and gases produced in a controlled manner to provide an environment with adequate temperature without excessive levels of humidity and toxic gases.

If ventilation fails, pigs may suffer distress or death by what is commonly called “suffocation” - implying lack of oxygen or excessive CO^2. In practice, death or suffering could result from any combination of excessive temperature, CO^2, or toxic gases from slurry or manure.

At the stocking rates typically encountered, animal heat production means that ventilation failure typically causes a temperature rise, and so most alarms are based partly or entirely on temperature.

Whilst regulations or insurers may require such alarms, little research has been carried out into their effectiveness. Detection by passing a temperature trigger point will clearly depend on the trigger point chosen, which is determined by the operator.

Thermostatic ventilation systems aim to keep room temperatures approximately constant with target temperatures in the range of 15 to 30°C according to the age of pig. When ambient temperatures are higher, systems cannot keep temperature close to target - typically systems will achieve around 3°C hotter than ambient when fully stocked at full ventilation. So, for example, a fully stocked finishing building will be around 28°C when it is 25°C outside, even with full ventilation and though the target temperature might be 18°C.

In this situation, pigs would not come to immediate harm. Although room temperature is higher than optimum, there is sufficient ventilation to allow them to lose their excess body heat.

Alarms are primarily intended to detect ventilation failure, but they are commonly referred to as “over temperature alarms”. This leads to the common misapprehension that temperature itself is the condition to be detected.

On this basis, alarm trigger points are often set simply on the basis of a temperature higher than that normally encountered - typically 30 to 35°C. This may be based more on avoidance of “false” alarms than on any particular ideas on detection of real failures.

It is generally assumed that room temperature would rapidly rise to high values, but there is little research data on temperature rise in normal commercial situations. Trials, if carried out, are typically by observing temperature rise for, say, 20 minutes, and it is assumed that temperature rise would continue.

There is no specific information on what duration of lack of ventilation is harmful, what temperatures would kill, cause suffering, or loss of production.

Although many millions of pigs are “at risk” from ventilation failure, it appears that the number which actually die (on an annual basis) is relatively low. A reasonable estimate is 1 in 10,000 to 1 in 100,000. That is, pigs dying from ventilation failure represent only 0.001% to 0.01% of total production. Leaving aside the welfare issues for the pigs concerned, this represents a relatively small overall production cost. (Though it should be noted that this loss is not evenly spread - a failure resulting in death is liable to affect many animals.)

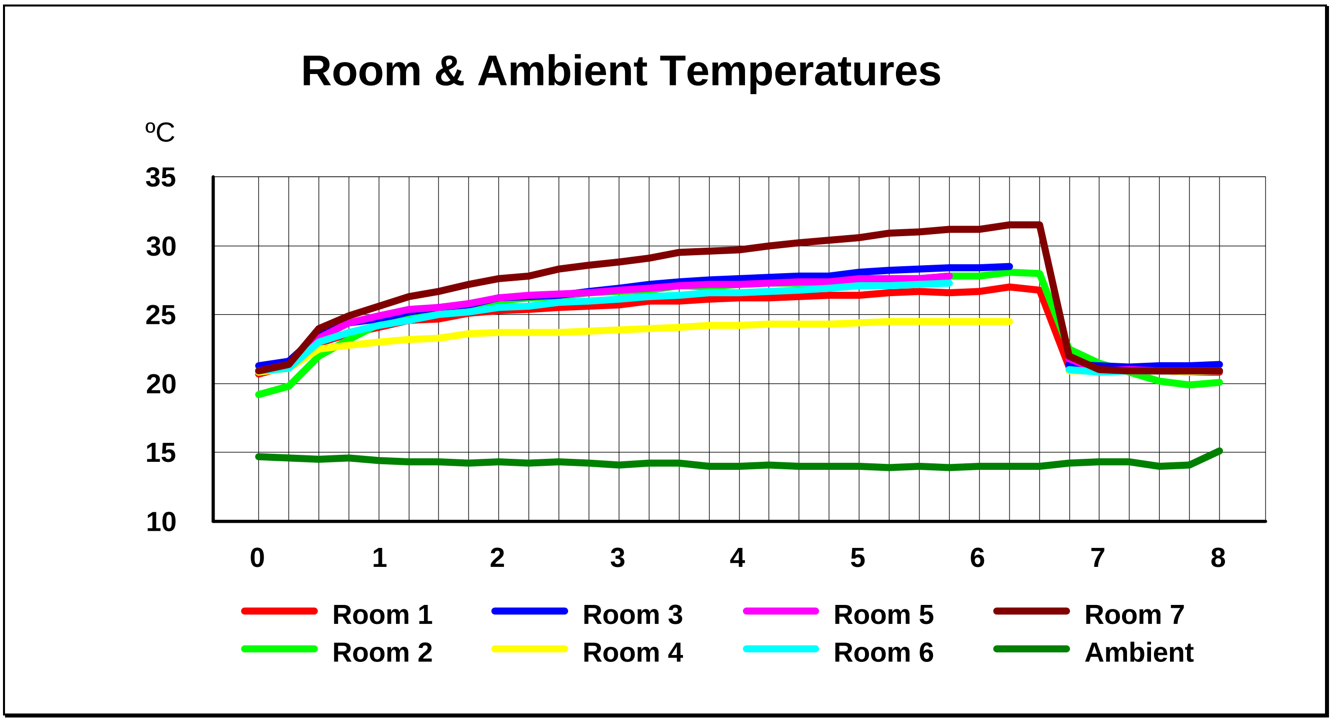
However, only incidents involving death of a significant number of animals seem to be regarded as are notable. If all animals survive a particular incident, it would tend to be regarded as a “near miss” - unfortunate, but of no consequence. There is good reason to suppose that there are many more such incidents, and that production losses (under performing for days or weeks subsequently) from this cause represent a much greater loss to producers as a whole than incidents involving death - probably by one or two orders of magnitude.

Data from actual incidents is sparse, and so it is deserving of study when encountered.

This paper studies two such incident where prolonged ventilation loss occurred, with temperature logging.

Whilst the specific results are not necessarily the same as for other situations, useful information can be drawn on the basic principles.

A ventilation failure incident in farrowing rooms



A group of 8 farrowing rooms within a single building are ventilated by extract ventilation systems with barometric air inlets. A mains power residual current leakage condition resulted in mains loss to all eight rooms. This led to loss of fan ventilation and creep heating at around midnight on a mild night in July, when ambient temperatures were around 14°C. Temperatures were being logged (for other purposes) at 15 minute intervals using a Dicam logging system (typical accuracy within 0.3°C).

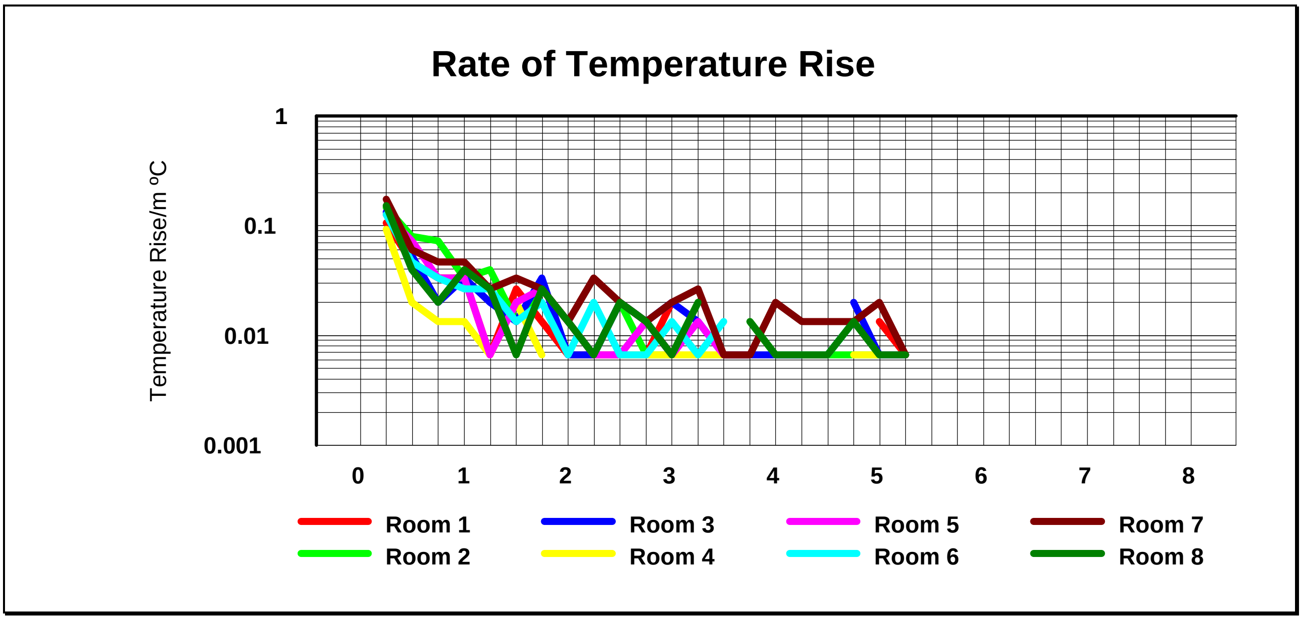
Ambient wind speed was around 6mph (2.7m/s), but the ventilation design is well protected from wind effects, and logging indicates minimal effect of wind.

The above graph shows the resulting temperatures. The times shown are relative in hours - the mains failure starts at about 15 minutes from the start of the temperature recording shown). Due to operational circumstances, no corrective actions were taken such as opening access doors to permit unpowered ventilation, as might be expected if an operator was in attendance within a short time. The situation was corrected approximately 6 hours later.

The data logging system was operating partially without mains power (on backup batteries), and some logging function ceased operating after 5 or 6 hours.

Whilst the starting temperature was similar in all rooms (Room 2 was set to a slightly lower temperature), the resulting temperatures show a large range - one reaching 32°C (Room 7), with another only 24.5°C (Room 4). This correlates with age of litters - piglets in Room 7 were much older, giving greater heat output.

Initial temperature rise is rapid but soon slows. Initial rate of rise is 0.10 to 0.15°C per minute, but this only lasts for 30 to 60 minutes. Thereafter, rise falls to only 0.007°C to 0.015°C per minute.



If we translate this into "time to trigger", we can see that small differences in a high temperature trigger point would have a large effect. Using Room 1 as an example :

Alarm Trigger Point	**Time Taken to exceed trigger point**
24°C	1 hour
25°C	2 hours
26°C	4 hours
27°C	Not exceeded

If a typical user setting of 30°C has been used, then only one of the rooms shown would have triggered (Room 7, in 4 hours), assuming its trigger system was accurate.

In marginally lower ambient temperatures, over temperature triggering would have taken much longer, if triggering had occurred at all.

In this incident, it does not appear that any sows died as a direct result. However, it clear that the welfare of sows and litters was significantly compromised, and productivity is liable to have been affected.

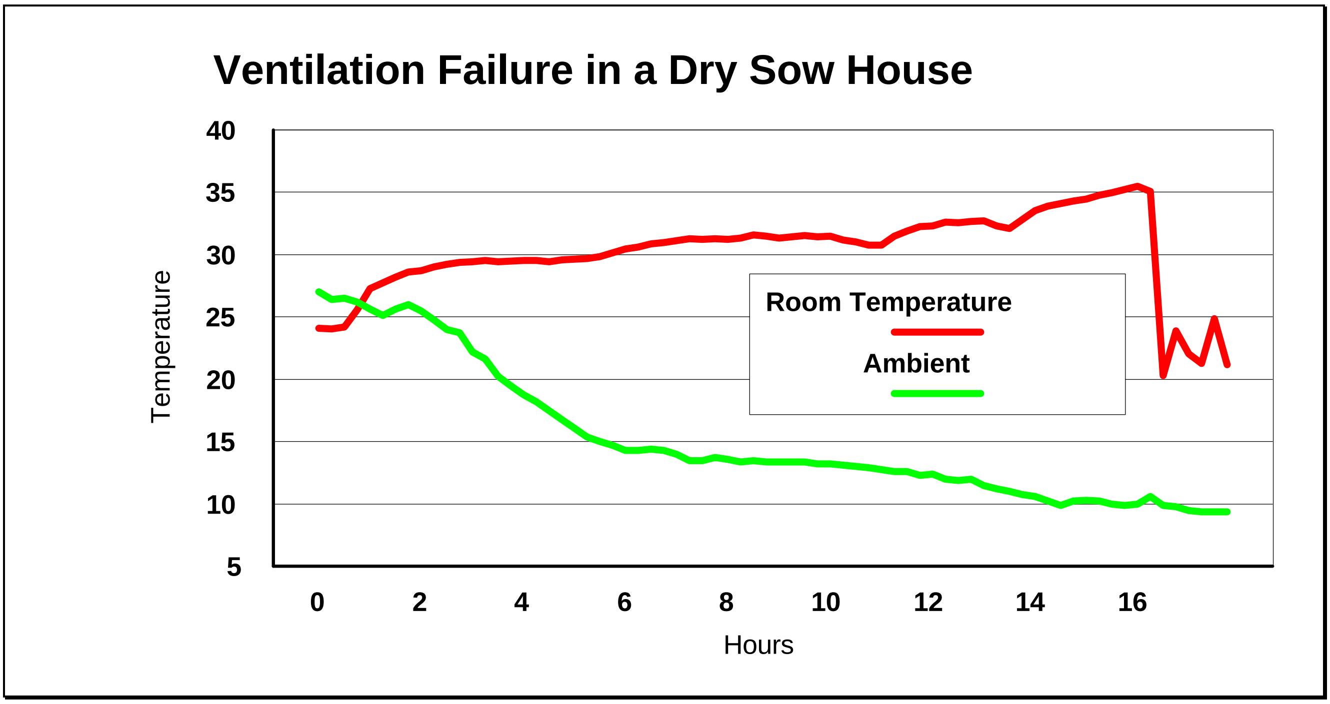
A ventilation failure incident in a dry sow and service house

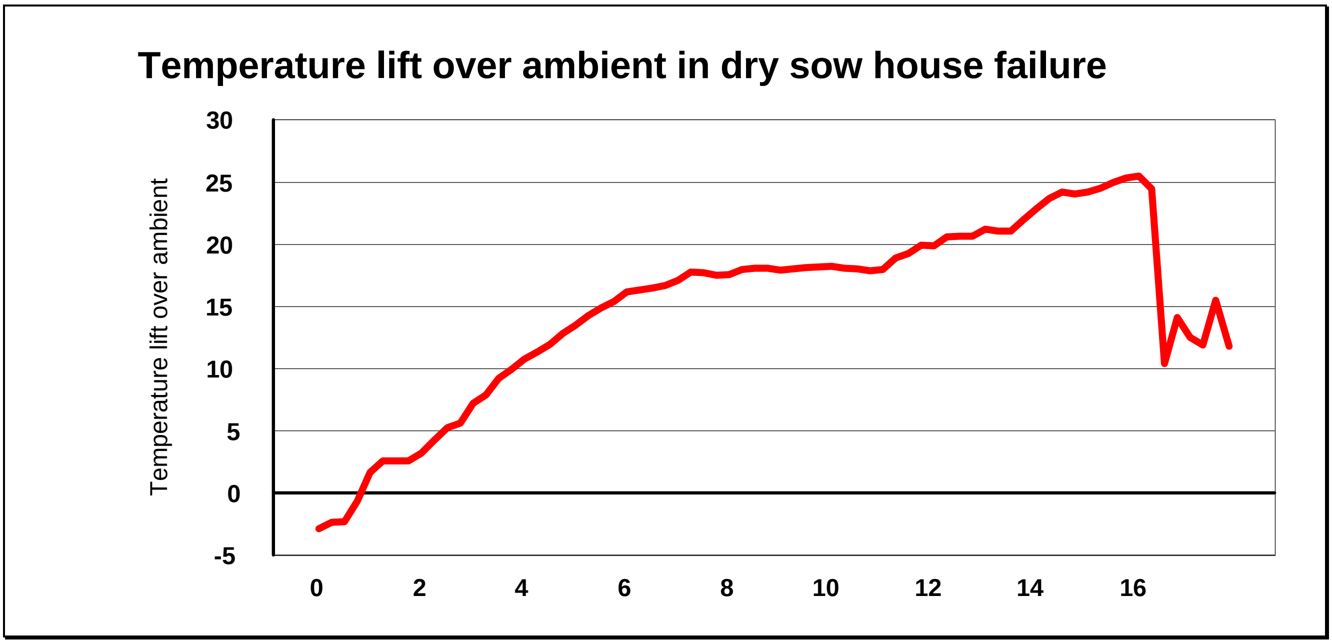
A large dry sow and service house suffered a ventilation failure when a circuit breaker was accidentally switched off in the early afternoon. The problem was not discovered and corrected until workers returned to the site about 16 hours later.

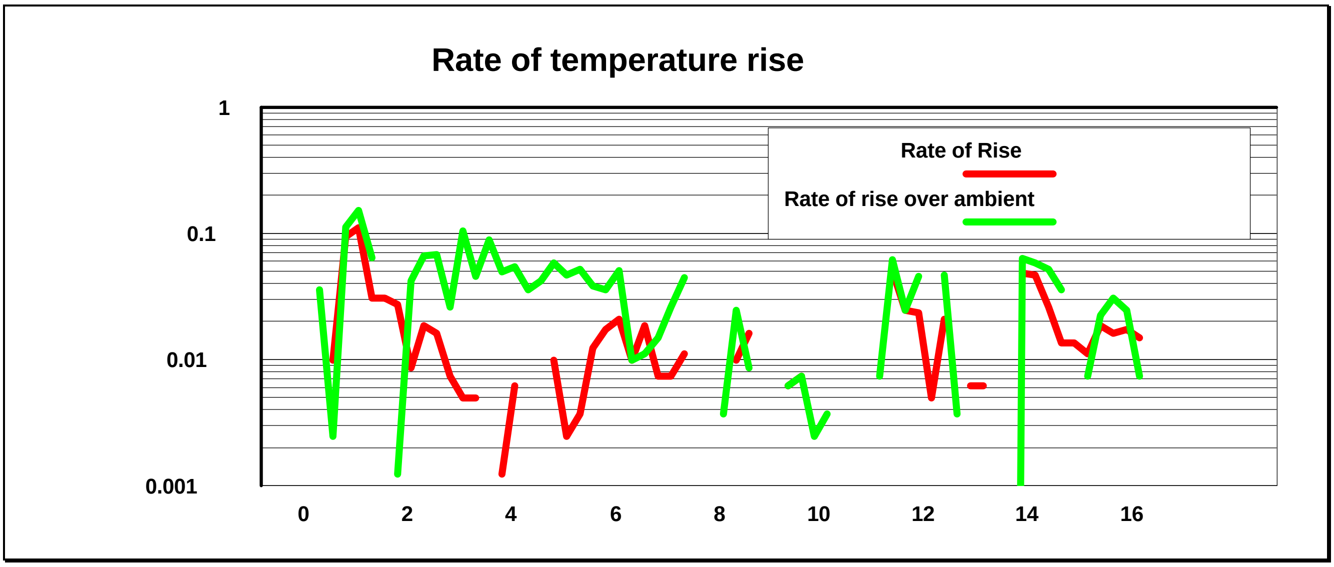
The building has evaporative cooling, so at the start of the incident, room temperature was lower than ambient. It should be noted that room temperatures as high as 33.5°C have been recorded in this room under exceptional ambient conditions, even with ventilation and evaporative cooling equipment fully functional.

After 16 hours room temperature had reached 35.5°C. The high temperature trigger was set at 36°C and over temperature was not triggered. In this incident, around 30 sows died, and many more aborted subsequently. Production losses can be assumed to be considerable, aside from welfare issues.

Whilst the general temperature drift is continually upwards, rise is slow or negative at some points. This is probably due to changes of wind direction and speed (inlet curtains are believed to have been open during the incident).







In this incident, a key feature is that ambient temperature was falling after the first 2 hours, which had a significant effect on the rate of rise of internal temperature. (In the first incident, ambient was almost constant.)

Whilst the high heat output from the animals meant a continued rate of rise at around 0.05°C/minute with respect to ambient, the absolute rate of rise was only around 0.01°C/m.

As with the previous incident, we can translate into trigger times at various trigger settings :

Alarm Trigger Point	**Time Taken to exceed trigger point**
27°C	<1 hour

29°C	2.5 hours
31°C	7 hours
33°C	14 hours
35°C	15.5 hours

General Discussion

In both incidents, there are significant issues of staff training and supervision in operation of electrical equipment, since this led to the sustained loss of ventilation. In the first case, the member of staff paid attention to the alarms, but not to ventilation. In the second case, the mains loss to fans seems to have been caused by human error.

The fact that sustained ventilation loss might have been avoided with better training does not make the results irrelevant. Ventilation loss could just as easily been caused in ways which would not have been immediately obvious.

The key issue is that *ventilation failure detection based on a fixed (absolute) High Temperature trigger point is questionable.*

In both cases, it is clear that significant suffering or risk of suffering and probably economic loss have occurred, before “excessive” temperatures as such were reached. That is - temperatures which might be experienced in normal operation, when ventilation was functioning.

A brief study of the underlying factors may be useful -

Temperature rise is caused by an excess of energy in the system. Energy is gained from the animals and lost by conduction through the walls and roof (in the absence of ventilation). Initially there is a large excess and room temperature rises rapidly. As room temperature rises, more is lost through the walls and so the excess is reduced and the rate of rise slows. Eventually, it would reach a steady state where energy gain from animals equals energy lost by conduction - at a certain temperature lift over ambient.

Regression of resulting temperatures show a good fit to an equation :

$T_l = a*b^t$

Where

T_l = Temperature lift over ambient at any point in time

t = time in minutes from ventilation loss

For example, in Room 7 (farrowing, first incident) :

Temperature lift = $6.18 * 0.17^{(t)}$ °C

Clearly, there are a number of factors which contribute to the overall equation - heat production (from animals and other heat sources), heat loss through the structure (i.e. insulation) and so on.

Modern pig buildings tend to have a typical insulation value around 0.5 to 1 W/m2/°C, but there are large differences in surface area ratios - smaller rooms have more outside (heat losing) are than large volume rooms. Well stocked finishing houses (at maximum pig weight) will have more watts per unit area than farrowing houses.

It’s not the aim of this paper to try to derive the equation to relate temperature rise to heat production, number of animals and so on.

The first crucial point is that the result is a temperature lift over *ambient* (outside) and **not** an absolute temperature.

The second is that the largest part of the temperature rise occurs in the initial stages - for example, that 2/3rds of the temperature lift which will occur in 4 hours actually occurs in the first 30 minutes.

So where trials have been carried out to look at temperature lift on losing ventilation - lasting 20 or 30 minutes - the temperature rises observed are not part of the temperature rise, but most of it.

Other factors will undoubtedly have some effect. For example, thermal stratification in a building will have an effect on temperatures measured at any particular point. The heat source (from pigs) has a limited source temperature; humidity may play a part.

Wind effects may have an effect, depending on building design. Heat sources - such as creep heating, which might be manually regulated may add to the heat burden, and so on.

Whatever the exact model., it is clear that a fixed high temperature trigger point is not adequate. Room temperature on its own - an “absolute” value - neither indicates whether ventilation is functioning nor whether the pigs are “safe”.

It is not safe to assume that any particular temperature will be reached “sooner or later”.

Pigs are at most risk when unattended (that is, when workers are not on site), which is typically 12 to 18 hours a day. Although it is not clear what period of ventilation loss might be harmful, it is evident that - as in the second incident shown - there is a clear risk of ventilation loss for this entire period if failure is not detected fairly quickly. Not least because it is probable that ambient temperature will be falling during this period, leading to slow rise or even falling temperatures after the initial rise.

Temperature alarms must trigger at the temperature reached within 60 minutes because temperature rise after that time is much slower and less certain. If a trigger would not be reached reasonably quickly, it may take a very long time, or not at all.

It might be tempting to conclude, since temperature based alarms are “fallible”, that they are useless. (Indeed, the very high trigger settings often found may be partly due to ignorance on the part of the user, and partly through a total lack of faith in them at all.)

However, there are good reasons for rejecting this idea.

Firstly, because these cases show that, in practice, temperature actually does (typically) rise when ventilation fails.

Secondly, because temperature can (with modern equipment) be measured consistently, reliably and accurately at reasonable cost. It may not be the ideal measure of whether ventilation is present, but it can at least be measured.

The problem is not that temperature is no good, but that temperature is (often) no good because of the way that it is used.

A trigger temperature of 30 to 35°C, applied summer and winter, to all or any pig buildings, is not good enough in itself to trigger reliably - perhaps at all, and certainly in any particular period of time.

To work adequately (or perhaps at all), a more sophisticated approach is required.

Regular manual adjustment of the trigger point is a possible method. The main problem with this approach is the work and dedication required. Outside temperature swings would mean adjusting several or even many times a day; apart from the extra work, it is very prone to error.

Adjusting automatically on the basis of outside temperature is another method.

In the Dicam “AutoSet Alarm” feature, room temperature is allowed an “operating margin” above Set Temperature, or above Ambient Temperature. For example, the room is allowed to be 5ºC hotter than set - or 5ºC hotter than ambient when ambient is above set. So the trigger point is automatically raised in higher ambient, but more importantly, reduced again when cooler.

(The method includes other refinements such as automatic double checking of ambient temperature reading, comparison of room sensor readings, and a backstop absolute maximum trigger temperature.)

In the first incident shown, this method would trigger within an hour or so in all but one of the rooms. In the second, a 5°C band would trigger in about 30 minutes.

In general, Set temperature is a good guide to the temperature which should be expected, and therefore significant deviations above it could be taken to indicate a problem (except when due to higher ambient). There are problems with this approach, clearly, when user “target” temperatures bear no connection to what can actually be achieved.

An algorithm based on rate of temperature rise could be possible. This method is used in fire detection systems, but it should be noted that the rate of rise in the event of a fire is orders or magnitude greater than rates of rise in a pig building following ventilation failure.

Detecting ventilation failure by temperature can never be “certain” in the sense that an alarm definitely will trigger if there is ventilation failure, but definitely won’t if there is not. It is more realistic to look in terms of probability.

With simple “fixed temperature” alarms, if probability of detection (in event of failure) is high, then probability of false activation is considerably increased also. (Increasing the trigger point reduces probability of false activation, but correspondingly reduces probability of “true” activation.

Other detection methods can improve or enhance detection probability. For example, more mains detection circuits, gas detection and so on. However, there is an inherent problem in terms of cost/benefit. Alarm systems do not produce a direct benefit in terms of animal growth or economic performance, only in reduction of loss. Since many producers are unaware of their actual losses from under performance, the focus is solely on death losses, which are relatively uncommon. Indeed, it required regulation in the UK before most producers installed systems at all, not least because many had never suffered a significant death loss.

Even if other methods are used, they should be in addition to, and not in replacement of a temperature based system. For example, adding mains detection to fan circuits would not replace temperature detection. In the context of reluctant spending in this area, and undoubted increase in maintenance costs, alternative or additional alarm factors are liable to have a relatively low rate of take up.

It should be noted that the “temperature rise” model for ventilation failure detection is only good for situations where the temperature without ventilation will be higher (than set temperature) without ventilation than with it. This is generally the case since ventilation removes heat. However, in cases such as flat decks in cool conditions which rely on heating as well, detection could be very uncertain if heating fails at the same time as ventilation. (Since this is most likely to occur on general mains failure, mains failure detection in addition is a higher priority.)

In the UK, regulations require that ventilation failure alarms are installed and “tested” weekly. However, there is no clear specification in terms of what or how detection is carried out. Testing is generally taken to mean that the equipment is checked to see that it functions within its own specifications, but there is no clear requirement to check that it will actually detect a failure in practice.

Taking the second incident as an example, the equipment was entirely capable of detecting the failure, but could not do so because of the way it was set and used.

It is quite probable that many - even most - systems would not detect a problem, either through capability and accuracy, or because of how they are set.

It is worth noting that accuracy and setting resolution of many electromechanical (thermostat) and low cost analogue systems is only around 3ºC - and common max min thermometers which might be used to check the equipment, are only slightly better. As we can see in these incidents, this would give a very wide spread of detection effectiveness.

Improving the temperature trigger algorithm can improve rate of detection, as well as resistance to “false” alarms. However, this is not possible with much of the existing alarm equipment installed and would require further investment. Clearly, this would require a change in attitude, awareness and understanding. User training will be a key requirement.

Above, we have suggested that triggering should be within 30 minutes or so, since the detection period is then almost indeterminate. A useful exercise would therefore be to switch off ventilation in mild or cool ambient conditions to observe the resulting temperature changes in the first 20 to 30 minutes, and carefully relate it outside temperature. The above model suggests that this temperature rise should be a good guide to trigger settings.

Conclusions

1. Increased room temperature can be an effective way of detecting ventilation failure, but many systems are probably ineffective.
2. High temperature alarms must trigger at temperatures which will be attained within 30 to 60 minutes of ventilation failure, or else there is a significant possibility of failure to trigger.
3. Simple fixed “High Temperature” triggers are not adequate. High temperature triggers must be adjusted to take ambient temperature into account.
4. Thermostats and cheap analogue temperature alarms are probably not adequate for current requirements in many installations due to low accuracy.
5. Many installations are in need of significant renewal.
6. Greater user training is required. Producers should allocate an annual budget.

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