APPENDIX 2

The use of laser to determine ammonia emission from farm buildings

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1 Introduction

The primary function of the laser is to measure the *mean* concentration of ammonia along a defined path; the principle is the absorption of infra-red light and measuring the attenuation. Essential to the method is the evaluation of ventilation rate – for naturally ventilated buildings, this often involves the release and monitoring of known amounts of additional ammonia. Typically the path of the laser will stretch across a building but there must be careful note of wind direction to ensure that the building is adequately represented. Thus the best location for a laser is across the opening downwind; a diagonal path (corner to corner) may only encompasses ~50% of the emission on the basis that it all originates from the floor. Emission of ammonia is deduced from the product of ventilation rate and ammonia concentration within the building.

Figure 1: laser apparatus set up outside the test building.

The apparatus used was a Boreal Laser Instruments “Gas Finder 2.0" which gives a continuous reading of ammonia concentration (Figures 1 and 2). This is set up at one end of the area to be monitored and a reflector placed at the far end; thus the laser traverses the room twice; the attenuation is measured and correlated to the concentration. Specific wavelength is used to the gas in question which lies in the infrared region for ammonia. The nature of the measurement ensures that a *mean* value for the room is produced. Observation takes place over a 2 to12 hour period; within this, a steady period of ventilation is chosen (minimum 10 minutes) and the corresponding mean concentration determined. Several such measurements would normally be taken over the observation period and a mean may be taken.

By itself the laser can not determine the ventilation rate which must be known if emission is to be deduced. This can be relatively straightforward for a forced ventilated building so long as there is information on the fan type and running time. For the naturally ventilated building, measuring what can be a highly variable and (sometimes) ill defined ventilation rate is much more difficult. When laser equipment is being used, a common approach is to release quantities of ammonia to act as a tracer gas.

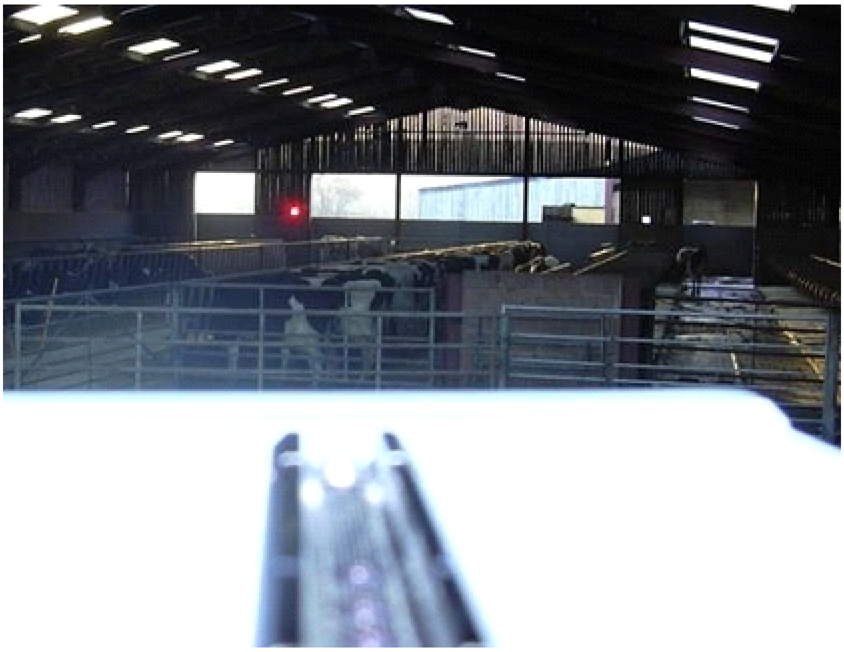

Figure 2: laser equipment (foreground) set up to send a beam across a farm building. The mirror reflecting the beam is just distinguishable in the distance.

Ventilation is deduced by the response of building concentration to such releases. There are two broad strategies that can be followed: firstly from a steady constant release of ammonia for a fixed period of time. In this case, ventilation is deduced by applying mass balance principles. The second method is that of a short release of ammonia followed by a study of the fall of concentration which is assumed to be a first order decay. In either case, the deduced ventilation rate can only apply to background measurements in the period of time just before and just after the planned release. Ventilation measurements can be extended if local wind data is known on the basis that ventilation rate is related to wind speed and direction. This is not necessarily an easy correlation but for buildings approximating to tunnel ventilation some simply models are possible. For this reason, local wind velocity is recorded using a sonic probe at the same time as monitoring emissions. It is normally worthwhile noting ambient and building temperature for a similar reason.

2 Emission correction factors

It would be rare for the air in the building to be evenly mixed and thus to have a similar concentration of ammonia throughout. Even if the release of ammonia (assumed to be mostly from the floor surface) was constant, the concentration of that leaving via the roof vents or via open ends can be expected to differ as the result of air movements through the building. As a consequence, some correction factor needs to be applied to the concentration value recorded by the laser beam; and in some instances, the beam may need to be relocated to ensure a more representative reading.

The situation is summarised in Figure 3 (below). The laser was conveniently located in one corner as shown with a beam following path [a] - there is a consistent wind down the building. With ammonia being released a point within the building but upwind of the laser, then all of the emission will theoretically pass though the laser beam. However, when considering the background emission from the floor, one can see that only that from area A will be covered representing in this example a theoretical 45-50% of the building according to geometry. Such is the basis of a correction factor necessary when determining emissions. Buildings and wind direction may not be so obliging as in this example thus correction factors need to be checked by controlled releases. This is followed by calculation of a theoretical emission and then

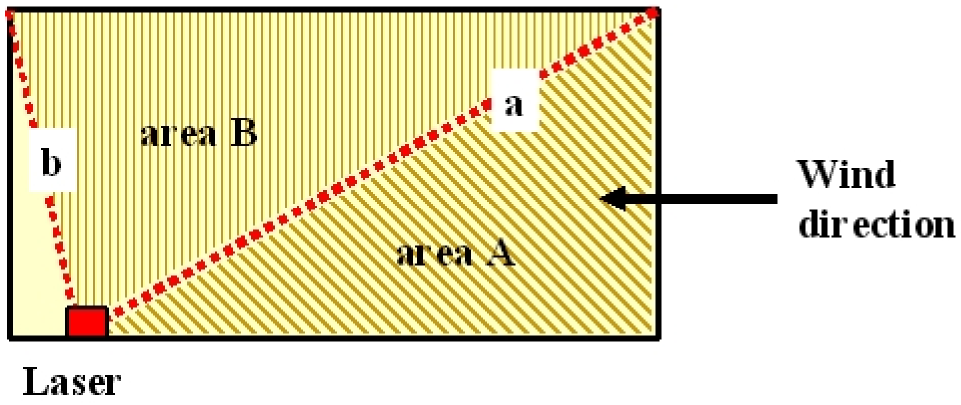

Figure 3: geometry of laser location with respect to the building being monitored.

comparison made with the release of ammonia known to have taken place. In some cases the correction factor turned out to be nearer 70% reflecting the loss of ammonia through other orifices such as roof vents.

To some extent, bisecting the building (line [a]) should allow for a fluctuating wind direction. If wind is consistent from one end of the building and ventilation approximates to tunnel ventilation, then relocation of the laser to line [b] may be a better strategy. It is noted though that the livestock buildings would be (necessarily) full of animals at the time of monitoring and access to all points within the building was not always possible.

3 Method 1, constant release of ammonia

This first strategy involves the release of a steady and known amount of ammonia from a cylinder. This can be monitored either via weight or, more conveniently via a flowmeter that has been previously calibrated. Achieving an even release of the gas is itself requires special attention. The concern is to ensure a rapid and even mix of the gas with the air so to quickly present the laser with a steady and consistent concentration of ammonia. In reality, this requires a series of hoses laid out on the floor providing multiple release points for the released ammonia.

The laser equipment is normally left running throughout. A continuous release of ammonia into building then starts at a known rate E g/min. When gas is being released and steady state conditions become evident from the trace, the settled concentration is noted as C2 which is the sum of that released deliberately and that from the animals and their manure. The gas is now switched off and time allowed for the background concentration (representing only that released by the animals) is determined as C1 g/m^3; this should be similar to that before the experiment but some variation can be expected as the result of fluctuating wind.

The graph in Figure 4 shows the typical plot achieved from the logged data from the laser. Difference in concentrations C1 and C2 are due to deliberately released ammonia.

$$E = (C2 - C1) * V$$

where V is the mean ventilation rate, m^3 per minute. Repeating the exercise several times enables a more reliable estimate of the ventilation rate for the day. Alternatively, each figure deduced can be used to produce a spot reading. In this case, note must be made of the problem of short term accumulation and release effects that can cause variations in emissions that do not represent the mean daily amounts.

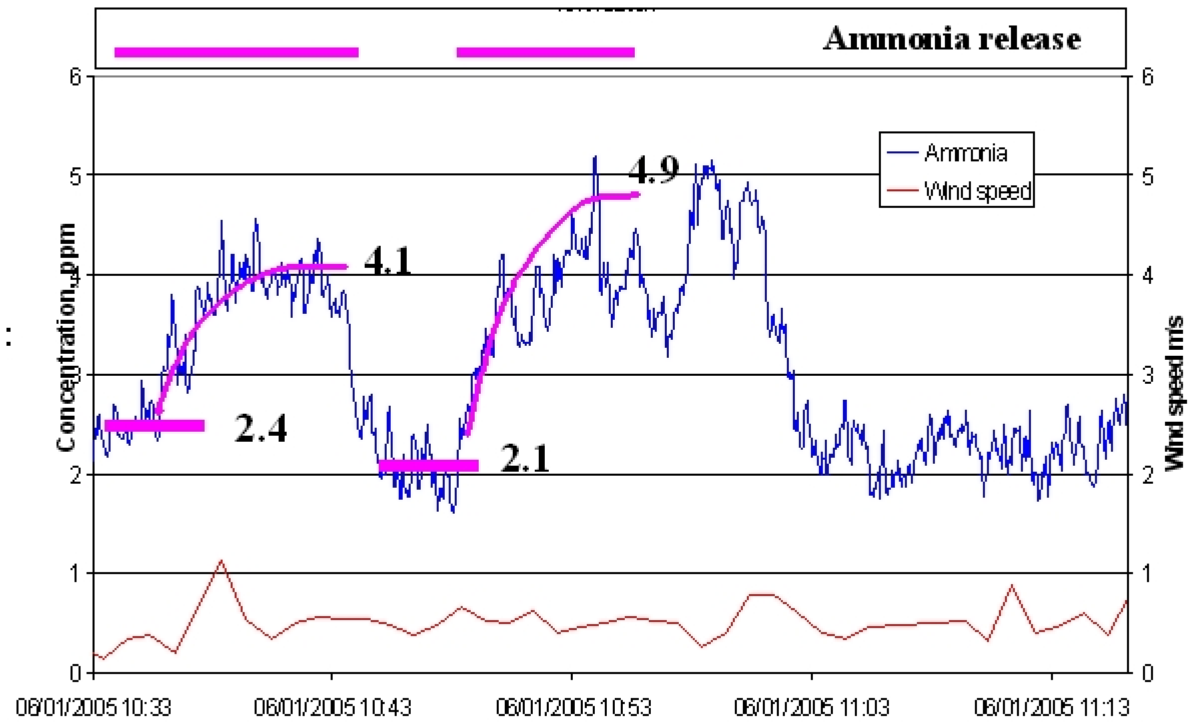

Figure 4: example graph of ammonia emission in response to two controlled releases of ammonia from a controlled source. Back ground emission is indicated in each case as well as the perceived steady state concentration following a period of release.

4 Method 2, monitoring decay curves following a short release of ammonia

The alternative approach is the release of ammonia "spike" over a short period of time then use ventilation model where:

$$C2 = C1 * \exp(k*t)$$

where k is a ventilation constant equal to building volumes per unit time (1/hour if time is in hours). This is a classical first order decay model applicable for well mixed systems with a steady state inflow and outflow. The injection of a tracer into the system over a brief period of time will see its concentration rise to a peak level followed by a first order decay. Solving this produces the often used equation above. It does assume a well mixed system which is not necessarily the case in a farm building; there is a second deviation from the model in that there are of course background emissions throughout. This latter point only greatly effects the curve shape as the concentration returns towards the low background values. Hence, curve shape is more reliably determined near the peak values; the following example demonstrates the procedure.

Figure 5 is an example trace showing a couple of pulses. Unlike method 1, the amount of ammonia released is neither critical nor is it necessary to know the amount. It is important thought that the quantity is enough to raise the measured concentration to a value several times the background amount.

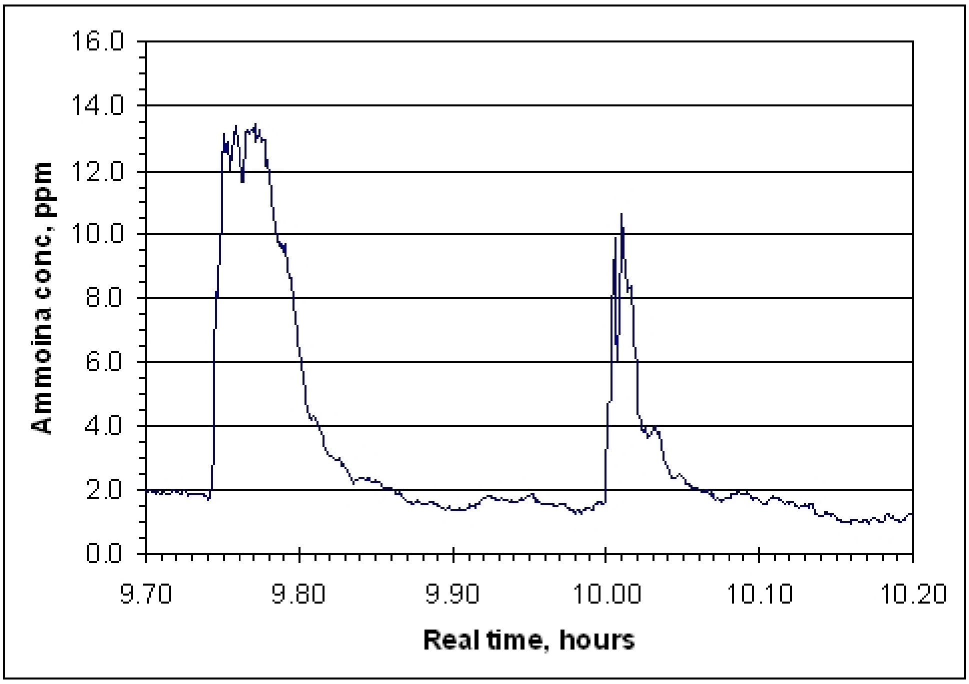

Figure 5: example of a record of measured concentration of ammonia in response to two injections of ammonia from a gas cylinder.

The next step is to identify the valid part of the graph which should represent a nice first order decay curve - these are shown in Figure 6 for the same example.

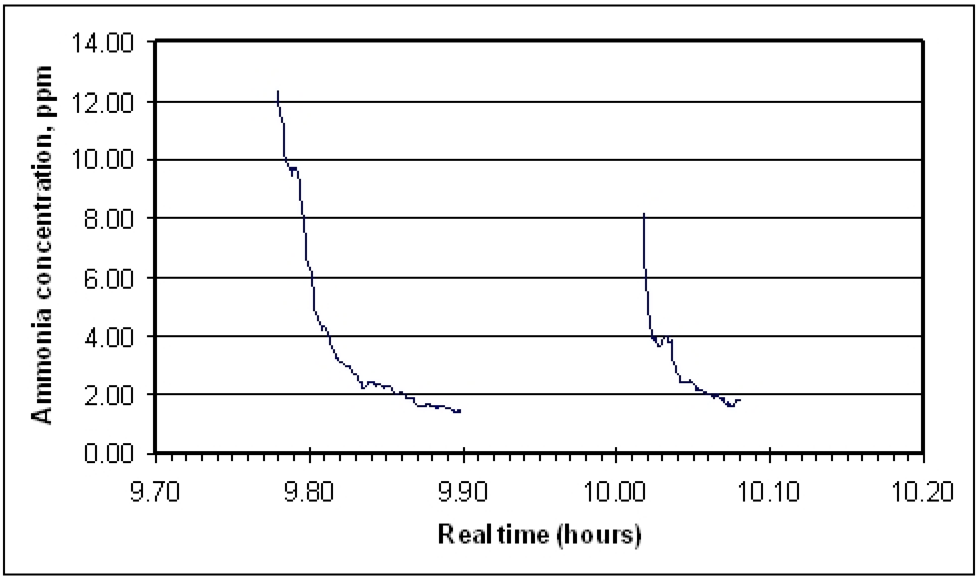

Figure 6: decay curves from previous example.

If we plot $\log_e C$ against t and fit best line between t1 and t2 then a straight line is expected of the form:

$$\log_e C = -k.t + \log_e C_o$$

this will have the slope of k which is the mean ventilation rate. C is the ammonia concentration in ppm and ***t*** elapsed time in hours. Figures 7 and 8 illustrate this plot for the two curves shown in Figure 6:

The curve in Figure 7, there is a clear inflection point which is assumed to be the result of interference from background emissions from the animals and building; hence, the steeper part of the curve is used in a line fit.

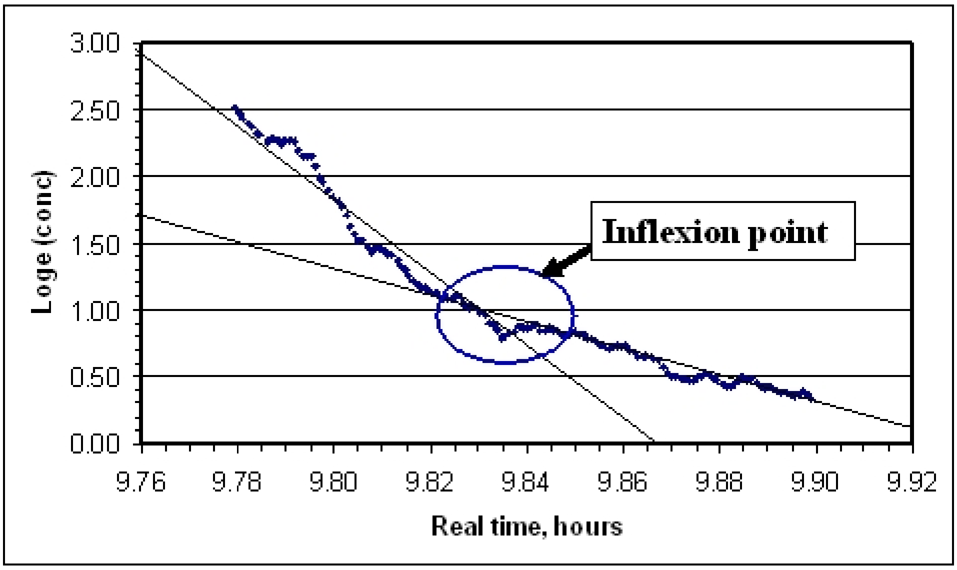

Figure 7: plot of logeC against time, t for first curve shown in Figure 6.

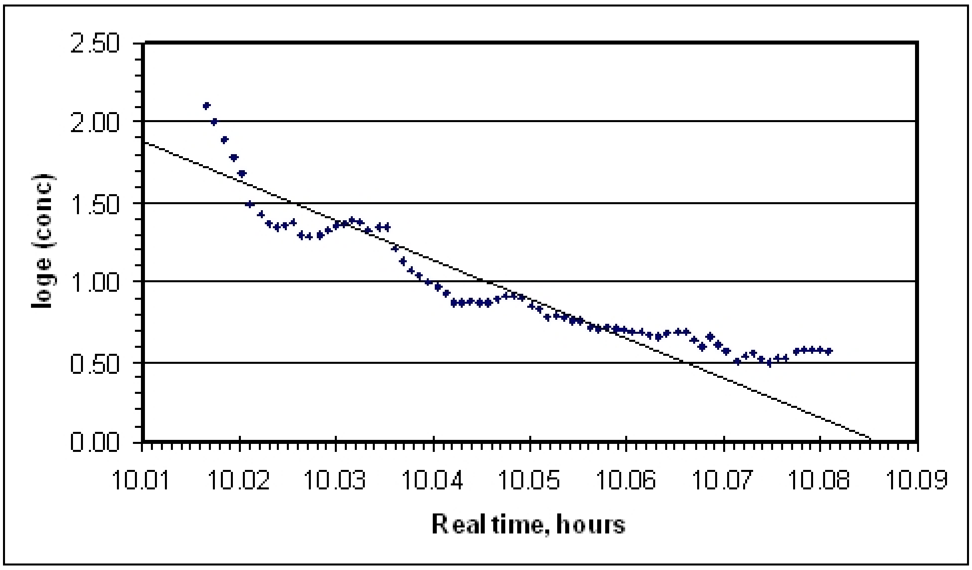

Figure 8: plot of logeC against time, t for the second curve in Figure 6.

For these two examples, k comes out as 29 and 25 hours-1 (or volume changes per hour). The volume of the building was measured as 7,710 m^3; thus the ventilation rates were 62 and 54 m^3 per second giving a mean of 58.

The building concentration at this time was estimated from the recorded concentrations before and after the controlled release as 1.25 ppm (volume/volume).

The emission factor in this case was determined as 0.7. Hence the ammonia emission at this point was:

$$(1.25*10^{-6}) * (58*3600*24) / 0.7 = 8.9 \text{ m}^3 \text{ per day}$$

The density of air at 0 deg.C is 1.284 kg/m^3 with a molecular weight of 29; ammonia is 17.

Density of ammonia is predicted as 17/29 * 1.284 = 0.75 kg/m^3

Published figures are a bit higher at 0.77 reflecting a none ideal quality of the gas.

We will take a value of 0.75 reflecting an air temperature of around 10 deg.C Thus the emission from the building is

8.9 * 0.75 = 6.7 kg ammonia per day in this example.

The building used had 140 cows at 600 kg mean weight.

This gives a specific emission of 40 g-ammonia per day per LU which is slightly higher than published figures but well within the range allowing for variability.

5 Wind models

Theoretically at least, one can produce correlations of wind velocity against ventilation rate to extend the model and robustness of the technique but a great deal depends on the building and typical ventilation patterns. The easiest buildings to deal with are those approximating to tunnel ventilation. In this case, ridge and side wall ventilation are relatively minor when compared to

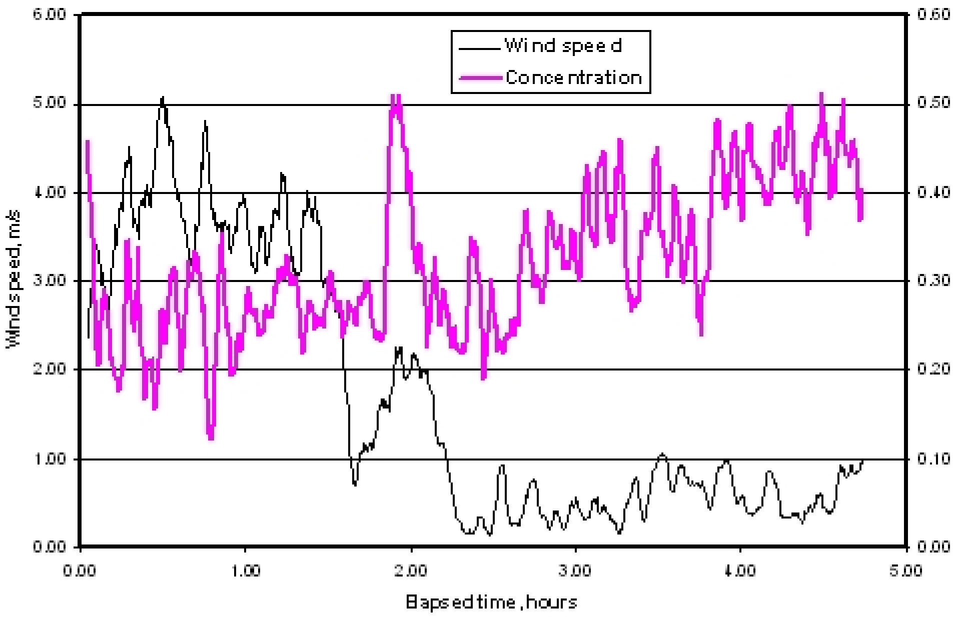

Figure 9: wind speed plotted against ammonia concentration in the livestock building.

the larger movements of air down the length of the building. This was the situation for the farm as Aller Barton. Figure 9 shows a plot of wind against measured ammonia concentration withing the building.

Two things are of note: firstly the inevitable fluctuations of the wind. This occurs at two levels: the short time period shows the natural fluctuations of wind even when appearing quite steady. The higher level shows a broad changes in wind speed throughout the period. Against the latter, the concentration measures responds relatively quickly providing a mirror image in the plot. In the light of this, one might expect there to be a linear relationship between wind speed and ventilation rate (on the assumption that he direction was predominantly along the length of the building. Figure 9 then can then be seen as reflecting the reciprocal relationship that is expected with emission being constant and the product of ventilation rate and mean concentration. Over a period of time, a number of measurements of ventilation rate were made for this building noting mean logged wind speed at the same time.

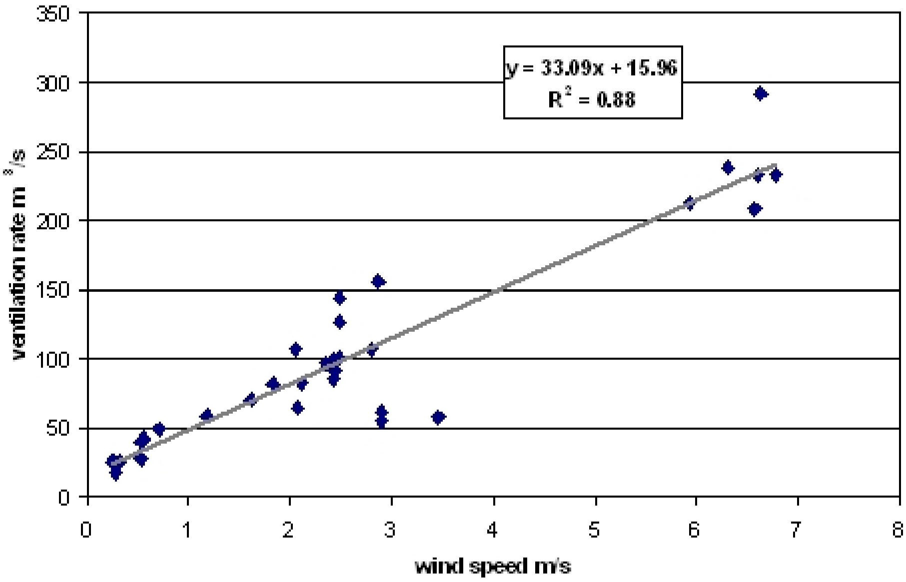

Figure 10: ventilation rate as a function of wind speed for a given building.

Plotting these (Figure 10) indeed confirms that there is a linear relationship in this case between wind speed and ventilation rate.