CL:AIRE

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technical bulletin

CL:AIRE technical bulletins describe specific techniques, practices and methodologies currently being employed on sites in the UK. This bulletin explains a best practice approach using complete continuous monitoring to assess the performance of ventilated underfloor voids.

Complete Continuous Monitoring in Underfloor Voids

1. INTRODUCTION

Post construction monitoring of passively ventilated underfloor voids is not routinely required. The design and performance of passive venting systems for ground gas follow well established principles and has been proven to be effective over the past twenty five years.

There are however occasions when there is value in carrying out monitoring of underfloor voids to help provide a more robust assessment of the risk posed by ground gas on a site. These are:

- Where gas membranes were included as part of the design but have been accidentally omitted during construction;
- Where verification of membrane installation was specified but has not been completed;
- Where there are doubts arising from the construction of the ventilated void;
- Where high gas concentrations and gas screening values (GSVs) indicate a Red classification, trial foundations/floor slabs can be constructed and monitored (or large scale flux chambers monitored over an extended period);
- On large sites where monitoring in the initial plots can be used to refine the site ground gas risk assessment to remove the requirement for membranes in later stages.

In such cases this bulletin explains a best practice approach using complete continuous monitoring. Complete continuous monitoring refers to the complete data set required to assess the performance of ventilated voids. The data includes gas concentrations in the void, and meteorological data that is obtained each time a gas reading is taken (wind speed, wind direction, barometric pressure, humidity and rainfall). *Note that this is different to the complete continuous monitoring data in boreholes, which also requires the continuous measurement of borehole flow rates.*

By collecting meteorological data alongside the gas concentrations in the void, the design calculations can be verified.

2. MONITORING POINT LOCATIONS AND INSTALLATION

The monitoring or sampling point for gas in the void should be located well within the void in an area where ventilation is likely to be less efficient. Monitoring very close to vents is not suitable because any gas in the void is likely to be diluted to negligible levels immediately behind the vent point. A typical monitoring position is shown in Figure 1.

Trying to pass the monitoring tube through air bricks with cranked ventilators behind them is not normally acceptable. In most cases the tube simply curls around in the cranked ventilator shaft and is monitoring atmospheric air (Figure 2). Even if the tube does enter the void it is usually close to the vent and is not measuring maximum likely concentrations. This should be allowed for if the data is used to assess the performance of the void.

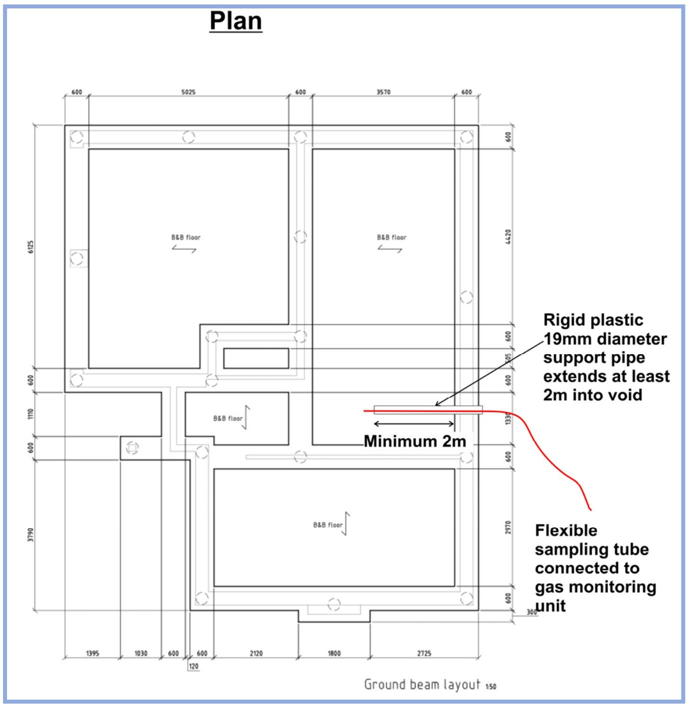

Figure 1. Location of monitoring point.

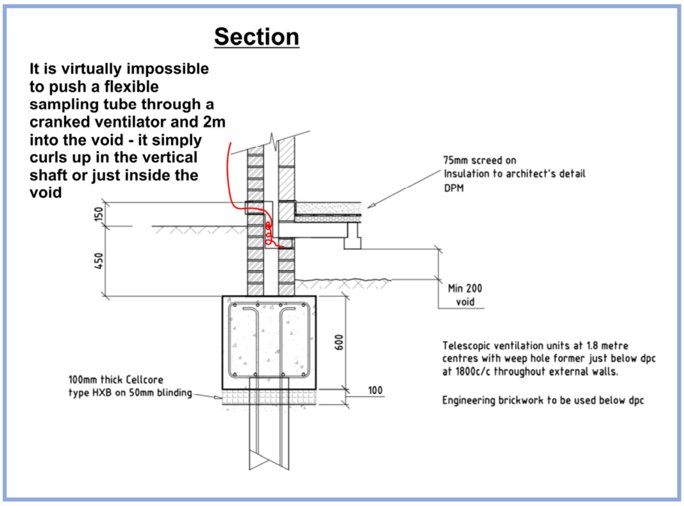

Figure 2. Incorrect approach to monitoring.

The monitoring point should be constructed as shown in Figure 3, by drilling into the void and inserting a rigid plastic pipe, into which the monitoring tube can be inserted. This may require a small excavation down the outside of the foundation to reach the level of the ventilated underfloor void.

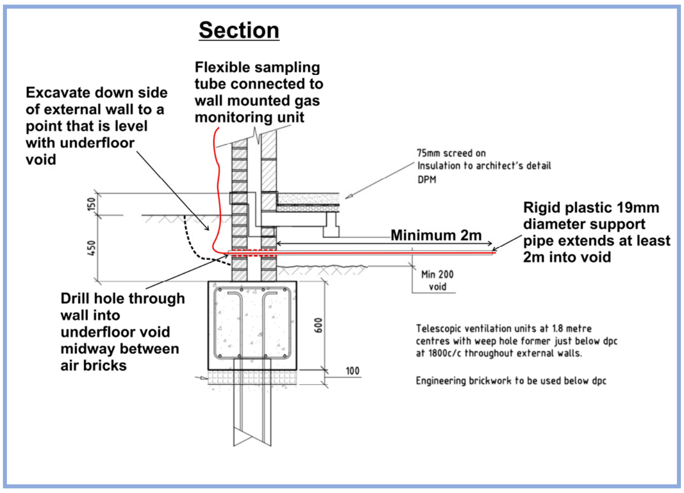

Figure 3. Monitoring point construction.

The approach described in this document requires that all the vents should be left open to allow the ventilation system to operate as designed. Once the monitoring has been completed and compared to predicted gas concentrations in the void the impact of some vents being blocked in future can be made (e.g. unintentional blockage by flower pots, etc or intentional boarding up to try and prevent draughts in the building).

It is not normally appropriate to try and seal the vents and use the void as a large flux chamber to try and estimate surface emission rates. The reason for this is that it is impossible to completely seal the vent and prevent air flow through it (the main route that gives significant flow is via the internal block wall and cavity, which are never fully sealed). If the void is to be sealed and used as a flux chamber it would require an instrument capable of measuring gas at ppm levels so that the analysis and estimation of surface emission rates could follow the guidance provided by the Environment Agency on flux chamber testing (Environment Agency, 2010). The analysis would also need to take account of the air leakage in the void.

3. DATA REQUIREMENTS FOR COMPLETE CONTINUOUS MONITORING IN VOIDS

When monitoring concentrations within the void, with the aim of assessing venting performance, the wind speed and direction at the time each sample is taken is required. This allows the measured gas concentration to be compared to the design value. Any correlation between gas concentration and changes in atmospheric pressure should also be identified. This will help to assess whether large drops in atmospheric pressure will adversely affect the performance of the venting system (i.e. worst case conditions). Monitoring of voids to date has shown that there can also be correlations between gas concentrations in the void and temperature or humidity.

The following data is required to allow a comprehensive assessment of the ventilation performance and design:

- Methane, carbon dioxide and oxygen concentrations in the void (or any specific gas that is being considered);
- Barometric pressure;
- Gauge pressure in the void at a suitably high resolution;
- Wind speed and direction;
- Rainfall;
- Humidity.

The weather data is obtained each time a gas sample from the void is analysed. This can be obtained from a local weather station or an onsite weather monitoring system if one is available. If the instrument used for sampling cannot be linked to a source of weather data, the data can be obtained later and linked to each reading manually.

The pumping time for each sample should be set by allowing for the length of the sampling tube and time it takes for a sample to reach the monitor from the void. Ideally the instrument should be located as close to the monitoring point as possible and the sample tube length minimised. Normally the baseline monitoring period will be a minimum of 60 seconds for the gas sample plus the time for the sample to travel the length of the tubing (calculated using the pump rate of the instrument, tube diameter and length). For example with a 3 m long tube at 10 mm internal diameter and an instrument pumping at a rate of 0.6 l/min, the sampling time should be in excess of 24 seconds to clear the gas in the line and ensure a fresh sample is taken from the void each time. A pre-sampling purge of 180 seconds would be more than sufficient to achieve this.

4. INTERPRETATION

The measured wind speed and direction is used along with the design gas surface emission rate to determine the theoretical concentration of gas in the void at any time. The design calculations for the ventilated void follow the approach for passive ventilation described in BS5925: 1991, a detailed explanation of which is provided in the Ground Gas Handbook (CIEH, 2008). An example set of calculations is provided in Appendix A. The gas emission rate would be estimated using either Fick's Law for diffusion or Darcy's Law for pressure driven flow following the guidance in Wilson (2008).

An example of the predicted gas concentration and that measured by continuous monitoring is shown in Figure 4.

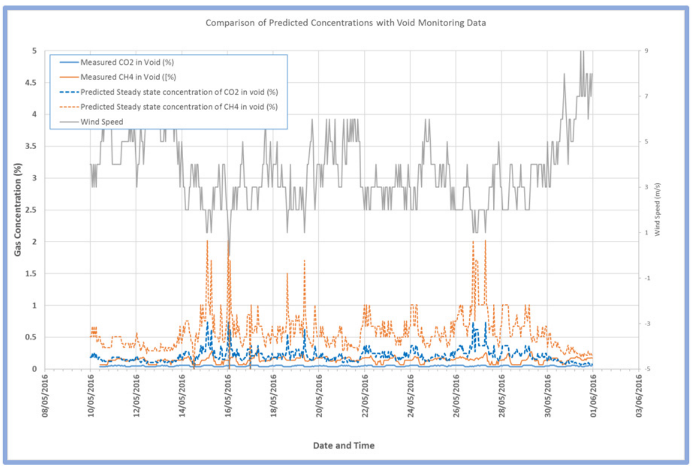

Figure 4. Comparison of predicted concentrations with void monitoring data.

An example showing how this approach has solved a ground gas problem in a development quickly and at minimal cost to the client is described in the following section. The gauge pressure in the void can also be used to assess the stack effect in the void (i.e. the difference in pressure between the void and the ground that could drive pressure-driven gas emissions). However, to do this a pressure sensor with a limit of detection of 1 Pa would be required, as the stack pressure is only likely to be a few Pascals.

5. CASE STUDY

The gas protection design for a development comprised a ventilated underfloor void below a block and beam floor slab, and a gas resistant membrane over the top of the slab. The specified gas membrane was changed by the builder and the installation was not verified. As a result the regulators would not sign off the land quality statement.

In this case the void monitoring and other assessment allowed the site to be classified as Green and therefore the 'absence' of the gas membranes was not a problem and the site was approved by the regulators.

The site history indicated that the only credible source of ground gas was a small shallow quarry located in one part of the site. It was infilled at some point between 1983 and 1991. The quarry had a pond in the bottom of it prior to being filled with excess material, excavated from a nearby motorway construction project.

The site investigation showed that the site was underlain by a thin layer of general Made Ground used to form previous ground levels (less than 1 m deep) and comprising red brown gravelly clay with fragments of coal, brick, clay pipe, slag and clinker. In the location of the quarry, Made Ground was deeper (up to 3.8 m) and comprised red brown slightly silty slightly gravelly clay with gravel of quartzite, siltstone, sandstone, burnt shale, flint, fragments of timber, brick slag and clinker. At the base of the quarry infill was a layer of soft grey black slightly gravelly organic clay with sandstone, burnt shale and fragments of black plant remains (thickness about 1 m, at depths of about 2.5 m to top of layer). Reference to British Standard BS8576: 2013 shows most of the infill is likely to be a 'very low' gas generation source and the organic layer a 'low' generation source.

The Made Ground is underlain by the Gunthorpe Member (part of the Mercia Mudstone Group) which typically comprises red-brown mudstone with subordinate siltstones and fine-grained sandstones.

There was no evidence of large volumes of fresh organic material within the Made Ground that could decompose quickly to produce large volumes of ground gas.

Gas monitoring results gave gas screening values (GSVs) well below the limit for Green classification following NHBC guidance (Boyle and Witherington, 2007) as shown in Figures 5 and 6, for methane and carbon dioxide respectively.

Despite the evidence indicating that there was no significant source of gas, the site was originally classified as Amber 2 because one methane result exceeded 1% v/v in the pond area (10% v/v) and carbon dioxide concentrations were recorded consistently at between 7% and 14% v/v). Analysis of the carbon dioxide concentrations outside the pond area showed that there was little oxygen

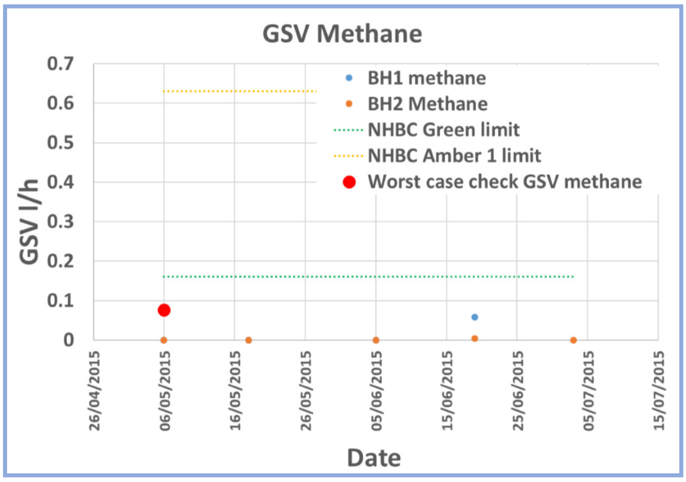

Figure 5. GSV methane

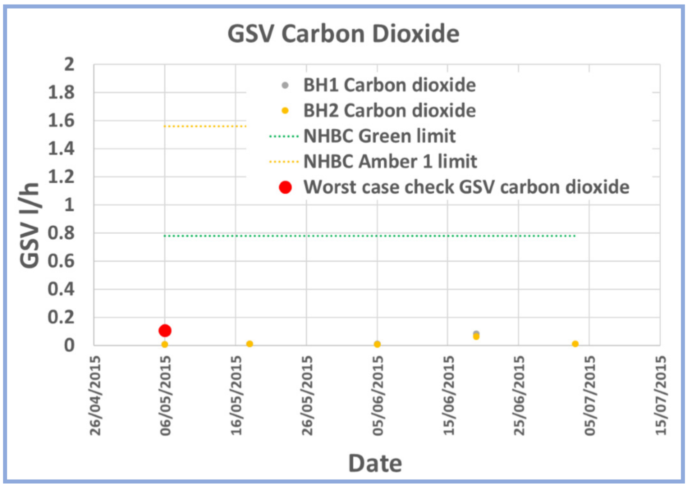

Figure 6. GSV carbon dioxide

consumption and that the most likely source was biological respiration (oxidation) of organic material (Figure 7). In the pond the evidence suggested some oxygen consumption and that the carbon dioxide was formed by oxidation of methane (the results are away from the Y-axis). In both cases generation rates are extremely low.

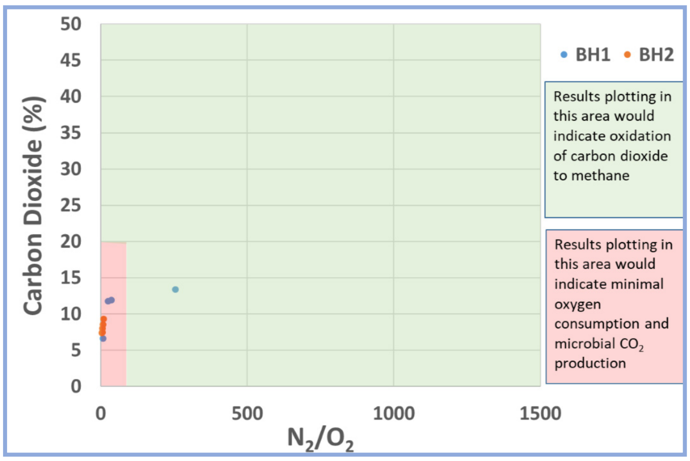

Figure 7. Carbon dioxide vs N2/O2

A continuous monitoring unit was installed in the void of a property constructed over the top of the infilled quarry for a three-week period. The results in Figure 8 show that negligible methane or carbon dioxide emissions into the void occurred, and that the

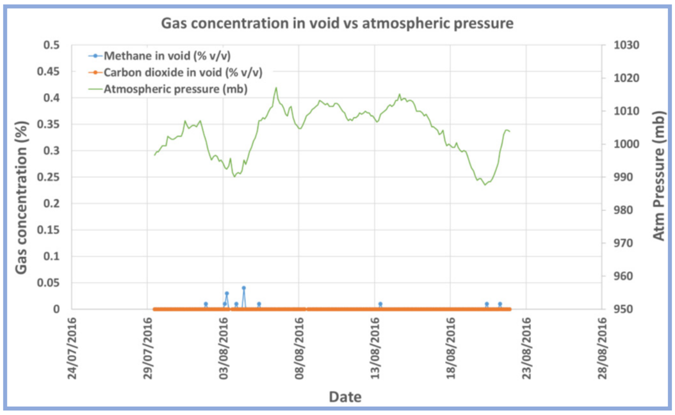

Figure 8. Gas concentrations and atmospheric pressure

measured gas concentrations are below the threshold limit of 0.25% methane and 1.25% carbon dioxide for the NHBC Green classification (a threshold concentration for carbon dioxide is not provided by NHBC but the value of 1.25% is appropriate in an unoccupied underfloor void).

The results also show that there may be a correlation between very slightly elevated methane concentrations in the void with drops in atmospheric pressure. However, given the magnitude of the drops in pressure and the very slight concentration recorded (all less than 0.1%) there is no significant risk of elevated methane concentrations occurring in the void. This is most likely because in this site there are no open pathways for gas migration, and the limiting factor on the response of surface emissions to changes in atmospheric pressure is the gas permeability of the ground. Schumann *et al.* (1992) suggested that advective soil gas flow in response to changes in atmospheric pressure can only occur where the soil is sufficiently permeable. It is also less likely to occur where the magnitude of the pressure drop is relatively small or the rate is gradual.

The measured concentrations were compared to those predicted by the design calculations (using the wind speed and direction from the continuous monitoring data and assuming steady state diffusion of gas from the ground). The measured concentrations were also well below those predicted by the design calculations (Figure 9) and did not rise significantly during periods of no wind. Thus there is negligible risk of gas concentrations exceeding 0.25% methane or 1.25% carbon dioxide during extended periods of no wind.

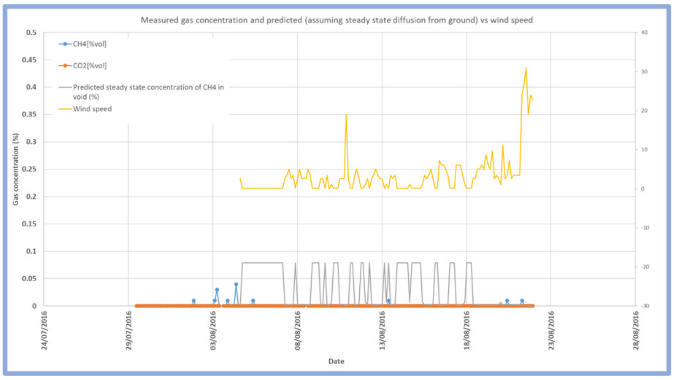

Figure 9. Measured and predicted gas concentration in void vs wind speed

The monitoring data combined with the analysis clearly showed that the gas membranes were not required. Therefore the absence of verification was not an issue and the site was approved by the regulator (note that in this case specific radon protective measures were not necessary).

6. CONCLUSIONS

The value of using continuous void monitoring has been to resolve the issues on the site quickly and in a cost-effective manner. The original plan was to leave the units installed for up to four weeks (longer periods may be proposed on higher risk sites). The units that were used are solar powered and therefore do not require visits to replace batteries. The units also upload the data via telemetry to a web-based platform. This allowed regular assessment of the results, and as soon as it became apparent that sufficient data had been obtained (after three weeks, two periods were observed where atmospheric pressure dropped below 1000 mb) the units were removed, giving a saving to the client. Additional confidence was provided by the absence of gas in the void during periods of no wind. In other cases monitoring periods may be extended because of the trends that have been observed, thus avoiding premature removal and a potential remobilisation to collect further data.

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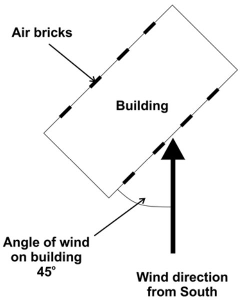
For further information and advice please contact:
Steve Wilson - stevewilson@epg-ltd.co.uk
Fiachra Collins - fiachra.collins@ambisense.net
Leo Phillips - l.phillips@enitial.co.uk

Appendix A. Example calculation to estimate design or predicted gas concentration in void for measured wind speed and direction (See Local Authority Guide to Ground Gas or Ground Gas Handbook, CIEH, 2008)

Measured wind speed, u_m , at nearest weather station is 2 m/s. Measured wind direction is from South. Orientation of building façades with air bricks on them is North West/South East. Therefore angle of wind on building is 45°

Therefore pressure coefficient from BS5925: 1991 *Code of practice for ventilation principles and designing for natural ventilation*,

$\Delta c_p = 0.7$



The height of the building is 5 m (the building height dictates the pressure on the wall and air bricks).

The wind speed from the weather station needs to be adjusted for local terrain conditions and height above ground level. Use the factors K and a from Table 8 of BS5925: 1991. This site is in an urban environment so K = 0.35 and a = 0.25

Therefore reference wind speed $u_r = u_m \times K \times z^a$ (Where z = height of building)

$= 2 \times 0.35 \times 5.0^{0.25} =$ 1.05 m/s

Total vent area of all air bricks on one side of the building, A_w , is 0.027 m^2

Now calculate flow of fresh air, Q

Assume the discharge coefficient for a narrow opening, C_d =0.61, which is a typical value for narrow openings from BS 5925: 1991. (This is a factor that correlates theoretical performance to actual performance)

The fresh air flow into the void, Q, is calculated using the following equation from BS 5925: 1991

$$A_w = \frac{Q}{U_r \times C_d \times \sqrt{\Delta C_p}}$$

$Q = 52.1\ m^3/h$

The design surface emission rate of methane by diffusion into the void is 0.081 g/s (this has been calculated for the site using Fick's Law and the properties of the soil (See Wilson, 2008).

Therefore using the Equation from Johnson and Ettinger (See Wilson, 2008)

Simplified equation from Johnson and Ettinger model (USEPA 2003)	$Q_{building} C_{building} = Q_{entry}$	(11)	$C_{building}$ = Equilibrium concentration of vapour in building under steady-state conditions (g/cm^3) $Q_{building}$ = Flow rate of fresh air into building (cm^3/s) Q_{entry} = Rate of vapour migration into building (g/s)

Concentration of gas inside building (or void in this case), $C_{building}$, = 5586 mg/m^3 or 0.9% v/v (note gas concentration in mg/m^3 is a gravimetric measurement and as a % is volumetric). The conversion takes account of the molecular weight of the gas using the following relationship

Concentration of gas in mg/m^3 = concentration of gas in ppm x molecular weight /24.45 (at standard temperature and pressure)

The number 24.45 in the equation above is the volume of a mole of a gas or vapour when the pressure is at 1 atmosphere and a temperature of 25°C

It is also significant that in periods of no wind (ie velocity is zero) the build up of methane has not exceeded 5%.