Department of the
Environment, Transport
and the Regions

Partners in Technology

Passive Venting of Soil Gases Beneath Buildings

Research Report

Guide for Design

Volume 1

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COOPER CLARKE GROUP PLC

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Ove Arup & Partners
Arup Environmental

Foreword

This Guide for Design presents the results of research undertaken by Ove Arup & Partners as part of the Department of Environment Construction Directorate's "Partners in Technology" Research Programme. Industry sponsors of the project were Cooper Clark Group plc and CORDEK Limited.

The research project was guided by a Steering Group which included a Department of the Environment nominated officer and industry representatives. The following individuals contributed to the project as part of the Arup research team or by participation on the Steering Group.

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The research report has been prepared by Dr V Paul and Mr R Owen of Ove Arup & Partners. The report has been subjected to peer review by an industry review panel which comprised:

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D C Meredith	Grace Construction Products
A Needham	Contest Melbourne Weeks
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The project team are also grateful to the Building Research Establishment for providing unpublished experimental data and research reports, which were used to formulate certain input assumptions for the CFD modelling.

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1. Introduction

There are many development sites in the UK underlain by made ground or natural deposits where the decomposition of minor amounts of organic matter has produced limited amounts of methane and carbon dioxide in the ground and may continue to do so at very low generation rates. Passive systems of gas protection are usually acceptable for such sites. Passive gas protective systems comprise a low permeability gas barrier, usually a membrane, over a high permeability ventilation layer. Hazardous soil gases migrating up into the ventilation layer are diluted and dispersed to atmosphere by natural phenomena, notably wind, temperature, and changing atmospheric pressure. The membrane acts as an additional secondary protective scheme and prevents gas entering the building through any defects in the floor slab during periods when natural forces are insufficient to cause sufficient dilution and dispersion.

Passive gas protective systems are described in documents produced by BRE(1) and CIRIA(3). However, the information in these documents is essentially limited to guidance on general principles of use.

This report provides quantitative information on the relative performance of various ventilation media and guidance on the design of passive gas protective measures. The report is intended to be used by consultants, engineers and contractors who are engaged in the design of buildings on or near low gas potential sites. The Guide is also intended to provide a reference document to regulators, such as Local Authority Building Control and Environmental Health Officers, to assist them in their assessment of ventilation schemes for particular developments.

1.1 Objective and Scope

The principal existing guidance on the applicability and design of gas protective measures for buildings incorporating naturally ventilated sub-floor ventilation is the Building Research Establishment Report 212(1) "Construction of new buildings on gas-contaminated land" which is referenced in the Building Regulations(2).

BRE 212(1) provides "construction principles" for passive gas protective systems for:

- houses and other small buildings; and for
- industrial, commercial and other large buildings,

on gas contaminated land. The solutions outlined in BRE 212(1) apply to methane concentrations in the ground of <1% by volume. For situations with higher concentrations it recommends that "further specific guidance be sought". This Guide for Design is intended to be part of that further specific guidance, complementing and extending the guidance in BRE 212(1).

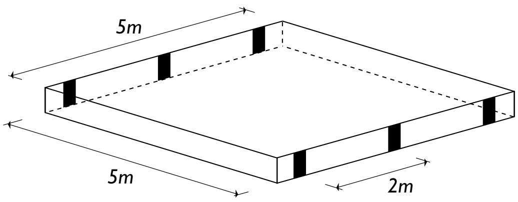
This guide is based on current practice and developed techniques. Further developments in risk management and methods of protection may influence the way in which the guidance may be used.

1.2 Method

The result and recommendations presented in this Guide for Design have been developed by:

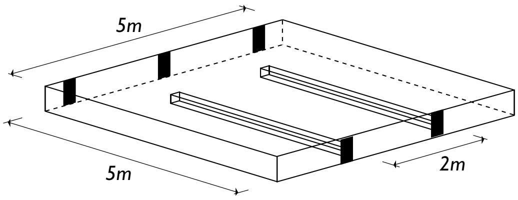
- the performance of a desk study review of passive gas protective systems;
- the undertaking of computational fluid dynamic (CFD) modelling to assess the performance of various different ventilation media and arrangements; and
- the application of Ove Arup & Partners' and the steering group members' experience in designing and installing passive gas protective systems.

Within the CFD modelling programme a combination of two and three dimensional (2D and 3D) CFD model simulations were carried out to allow calculation of ventilation flow patterns, pressure and gas concentrations. The ventilation systems were modelled on two idealised foundation widths (5m and 30m) with side vents on two (front and rear) sides only. The models used in the CFD simulations are shown in Figures 1 and 2. A range of applied pressure differentials was considered to represent wind speeds which would be exceeded 95% to 55% of the time, based on annual mean percentage frequency data for Birmingham, Bournemouth, Edinburgh and Glasgow. The CFD calculations were run to define steady state conditions of pressure, flow and concentration in the ventilation layer. A summary description of the modelling and example output is included in Volume 2.



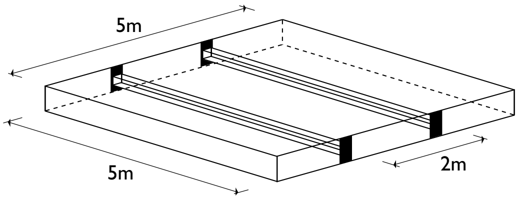
MODEL 1
Ventilation Media:
• Open void (200mm & 400mm)
• Gravels (20mm & MOT Type 1)
• Geocomposite blanket (Geofin 40)
• Polystyrene void former (VENTFORM-80,100,150 & 200)

Side Ventilation:
Air bricks at 2m centres on two opposite faces



MODEL 3
Ventilation Media:
Gravel blanket (20mm or MOT Type 1) with 100mm ID slotted pipes 4m long connected to side vents at one end

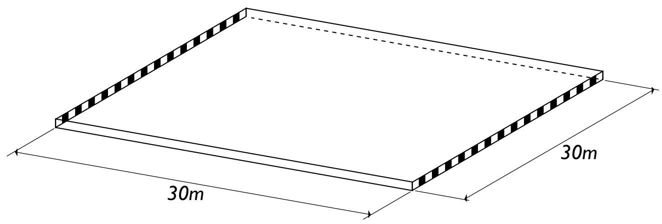
Side Ventilation:
Side A - Air bricks at 2m centres
Side B - Low level riser (100mm ID) connected to each perforated pipe



MODEL 6
Ventilation Media:
20mm gravel blanket, 200mm thick, with 5m long 100mm ID slotted pipes connected to side vents at both end

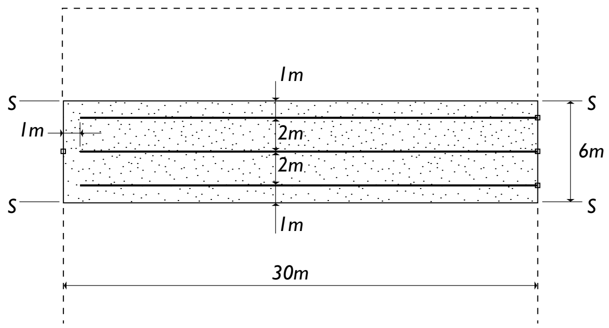
Side Ventilation:
A low level riser (100mm ID) connected to each perforated pipe on two opposite faces

Figure 1 CFD Models for 5m x 5m Wide Foundation



MODEL 2
Ventilation Media:
- *Open void (200mm & 400 mm)*
- *Gravels (20mm & MOT Type 1)*
- *Geocomposite Blanket (Geofin 40)*
- *Polystyrene void former (VENTFORM-80, 100, 150 & 200)*

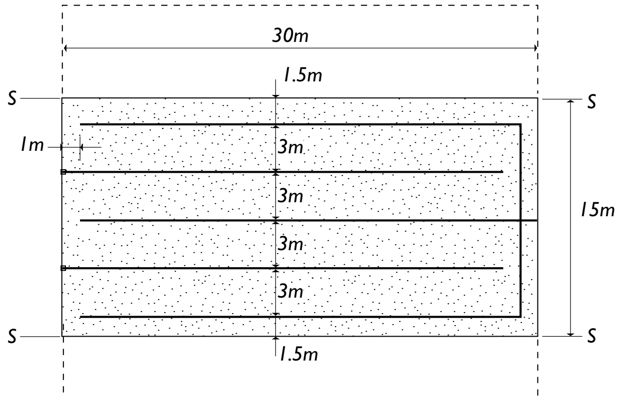
Side Ventilation:
- *Air bricks at 2m centres, or*
- *Gravel pit at 2m centres, or*
- *Low level riser at 2m centres, or*
- *Roof level cowl at 6m centres*



MODEL 4
Ventilation Media:
Gravel blanket (20mm or MOT Type 1) with100mm ID slotted pipes

Side Ventilation:
Side A - Air bricks at 6m centres
Side B - Low level risers at 2m centres

S - S : Line of symmetry



MODEL 5
Ventilation Media:
20mm gravel blanket with 100mm ID slotted pipes

Side Ventilation:
Side A - Air bricks at 6m centres
Side B - Low level riser at 15m centres

S - S : Line of symmetry

Figure 2 CFD Models for 30m Wide Foundation

2. *Background*

Passive gas protective systems for buildings are applicable to the majority of development sites where gas protective measures are required. Such sites may be:

- overlain by a layer of mixed fill material (made ground) or industrial/commercial waste material which contains limited amounts of biodegradable organic matter;
- underlain by soils which have a high organic content, eg. peaty soils;
- underlain by Coal Measures and/or shallow underground mine workings;
- affected by soil gases migrating laterally from a nearby source of underground gas.

Passive systems are not suitable where large volumes of gas are migrating to the surface, such as recent domestic and industrial landfills. However, such sites are precluded from domestic housing development and are generally also unsuitable for industrial or commercial development without extensive protective measures. The decision to employ a passive, rather than an active system, should be based on a full assessment of sufficient and appropriate site investigation data, the intended layout and use of the building, and the proposed structural details. Steps in the design procedure are outlined below.

Step 1 - Site Investigation

- Desk Study
- Logging,Sampling & Testing
- Gas Monitoring

↓

Gas Regime for Site

Step 2 - Design Requirements

- Gas Regime
- Size & Type of Buildings
- Type of Occupancy

↓

Active or Passive Measures
Target Concentration

Step 3 - Detailed Design

- Structural Constraints
- Internal Environment & Usage
- Cost
- Ease of Construction
- Performance of Alternative Media
- Maintenance/Durability
- Control/Building management

A recently published review on "Protecting Developments from Methane" by CIRIA(3) analysed more than 100 case studies where active or passive gas control measures were implemented. The report classified the gassing regimes found on the case history sites within 6 Characteristic Situations, as defined and reproduced in Table 1 below. The highest measured parameter, either methane or carbon dioxide concentration, and/or emission rate were used to define the Characteristic Situation for each case history site. The review(3) showed that, up to the time the report was prepared, passive gas protective measures had been used for residential housing developments up to and including Characteristic Situation 3, and in commercial developments on sites up to Characteristic Situation 5 (where the system utilised was an open void). Active gas protective systems had been used for commercial/ industrial sites with Characteristic Situation 4 to 6 conditions.

Table 1 **General Type of Gas Regimes** (after CIRIA Report 149)

Characteristic Situation	Gas Regime in Ground		
	Methane (% v/v)	Carbon dioxide (% v/v)	Emission rate[1] (m/s)
1	<0.1	<1.5	Not detected
2	>0.1 - 1.0	>1.5 - 5	Not detected
3	>1 - 5	<5	Not detected
4	>5 - 20	<20	<0.01
5	>20	>20	>0.01 - 0.05
6	>20	>20	>0.05

[1] Emission rate values measured as equivalent total gas flow velocity from a 50mm diameter borehole .

3. *Site Investigation Requirements*

The performance of an appropriate and adequate soil gas investigation is a crucial element in the design of an effective passive gas protective system. It is essential that the source(s) of the soil gases are clearly identified to allow assessment of the rate and duration of future gas generation.

Soil gas investigations should be incorporated into ground investigations of all sites overlain by filled ground, sites close to areas of landfill, former coal workings or sites where there is the potential for soil gases from natural deposits. Guidance on the planning, execution and interpretation of gas investigations has been published by CIRIA in the following reports:

- Methane investigation strategies. CIRIA Report 150(5);
- Interpreting measurements of gas in the ground. CIRIA Report 151(6);
- The measurement of methane and other gases from the ground. CIRIA Report 131(7).

The scope of the gas investigation should be consistent with the above guidance and should be sufficient to establish the gas regime of the site.

As a minimum the investigation should comprise repeat measurements of atmospheric pressure, gas concentrations, differential pressure and emission rate (flow or velocity) taken in carefully constructed gas standpipes. For each round of gas measurements information on changes in atmosphere pressure and rainfall just prior to (24 hours previously) should also be reported.

4. *Factors Influencing Ventilation Performance*

4.1 *Meteorological Conditions*

4.1.1 Wind

Wind is usually the principal driving force for dilution and dispersion of gas within a sub-floor ventilation layer. Wind movement around buildings creates areas of higher pressure (on the windward side) and areas of lower pressure (on the leeward side). This causes a pressure gradient across the ventilation layer. Under steady state conditions fresh air enters the ventilation layer on the windward side and migrates through the layer, exiting on the leeward side mixed with soil gas intercepted by the layer. For responsive ventilation layers (such as voids) wind induced pressure driven flow is reasonably approximated by steady state assumptions, particularly for moderate wind speeds. However, for less permeable media (such as gravels), steady state pressure driven flow is an over simplification, only developing with sustained periods of wind from the same general direction.

4.1.1.1 Wind Speed

Ten year (1/1/81-31/12/90) mean wind speed data for weather stations in Birmingham, Bournemouth, Edinburgh and Glasgow have been considered. These data show, recorded on a 10m high weather mast, the wind speed exceeded 3.09m/s at least 55% of the time during the monitoring period. The data also shows that a windspeed of 0.5m/s was exceeded at least 94% of the time during the monitoring period at the 4 locations.

More recent windspeed data collected by BRE, as 10 minute average data on top of a 15m high weather mast, showed that for the period 5 October 1995 to 5 October 1996 the median wind speed was 2.4 m/s. A summary of the BRE wind speed data is given on Table 2.

Table 2 Summary of BRE Wind Data

Month	Mean Wind Speed (m/s)	Median Wind Speed (m/s)	Number of 10 min No Wind periods	Maximum Time with No Wind (min)
October 1995	1.98	1.67	143 (3.2%)[1]	170
November 1995	2.12	1.96	48 (1.1%)[1]	50
December 1995	2.26	1.92	16 (0.4%)[1]	50
January 1996	2.87	2.81	9 (0.2%)[1]	10
February 1996	3.4	3.2	27 (0.7%)[1]	40
March 1996	2.59	2.44	4 (0.1%)[1]	20
April 1996	2.36	2.19	17 (0.4%)[1]	50
May 1996	3.36	3.37	29 (0.6%)[1]	50
June 1996	2.21	2.11	79 (1.8%)[1]	80
July 1996	2.3	2.21	129 (2.9%)[1]	340
August 1996	2.3	2.13	91 (2.0%)[1]	190
September 1996	2.66	2.53	55 (1.3%)[1]	160

[1] % of total time with no wind.

4.1.1.2 Pressure Due to Wind

The dynamic pressure due to wind is given by the equation:

$P = {}^{1}/_{2}\, \rho V^2$ where P = pressure due to wind (Pa)
V = wind velocity at the height of the building (m/s)
ρ = density of air (kg/m^3)

The mean surface pressure (p) which acts on the side of a building is given by:

$p = P_{at} + Cp.\ {}^{1}/_{2}\rho V^2$ where P_{at} = local atmospheric pressure
Cp = pressure coefficient

Pressure coefficients are specific for different locations on a building and for particular wind angles relative to the orientation of a building.

Values of pressure coefficients, derived from wind tunnel tests, for different locations on a building, different wind angles and different types of shielding are given Technical Note AIVC44 "An Analysis and Data Summary of the AIVC's Numerical Database"[13]. The dynamic head across buildings, based on these pressure coefficients, are given in Tables 3, 4 and 5 below.

Table 3 Dynamic Head across Low Rise Buildings (up to 3 stories) with Length: Width Ratio of 1:1 (from Technical Note AIVC44)

Shielding	Dynamic Head Wind Angle Relative to Building	
	Perpendicular	**45°**
None	0.9	0.75
Non-uniform	0.6	0.45
Uniform	0.45	0.35

Table 4 Dynamic Head across Low Rise Buildings (up to 3 stories) with Length: Width Ratio of 2:1 (after Technical Note AIVC44)

Shielding	Dynamic Head Wind Angle Relative to Building	
	Perpendicular	**45°**
None	1.2	1.05
Non-uniform	0.75	0.66
Uniform	0.36	-0.26

Table 5 Dynamic Head across a High Rise Building (91m tall) at various heights for Wind Angle of 0° (after Technical Note AIVC44)

Relative Height of Surrounding Buildings	Dynamic Head		
	Top	**Middle**	**Bottom**
1/6	0.98	0.86	0.6
1	0.46	0.28	0.43

4.1.1.3 Assumption Used to Assess Ventilation Performance in CFD Modelling

The ventilation performance of the various ventilation media have been assessed at wind speeds of between 0.3m/s and 3.0m/s. For each wind speed a dynamic pressure was calculated using the equation in sub section 4.1.1.2 above. The calculated equivalent wind pressure was applied as $+^1/_2$ a dynamic head to the vents on the windward side and $-^1/_2$ a dynamic head to the vents on the leeward side, giving a pressure differential of 1 dynamic head.

The pressure coefficients given in Technical Note AIVC44(13) show that this assumption is reasonable for buildings in an open environment but may be considered optimistic for buildings in a semi-urban or urban environment. It should also be noted that for passive ventilation systems, the pressure coefficients of interest are those very low down on the wall of the building, just above the ground. These coefficients are likely to be smaller than those given in Technical Note AIVCE 44(13). A full discussion on the pressure coefficients near ground level is given by Hartless(14).

The effect of changing the dynamic head on the results of the CFD modelling is similar to using a lower wind speed in the calculations. For example reducing the dynamic head difference from 1 to 0.6 (as for low rise buildings with non- uniform shielding) is equivalent to using a wind speed of 2.3m/s in the CFD modelling where dynamic head difference is 1.

4.1.2 Temperature

The temperature within the ventilation layer is controlled by the temperature of the overlying concrete slab and the underlying ground and will remain relatively constant on a seasonal basis. In contrast, external air temperatures vary both through a daily cycle and on a daily basis. When external temperature is less than the ventilation layer temperature, gas will be encouraged to exit the ventilation layer through buoyancy effects. However, when the external temperature is greater than the temperature in the ventilation layer gas dispersion to atmosphere will be suppressed.

4.1.3 Atmospheric Pressure

The emission of gas from the ground surface is known to be influenced by atmospheric pressure(4). The rate of pressure change has been shown to be more important than the absolute value. Gas emission from the ventilation layer as well as gas emissions from the ground into the ventilation layer will be greatest when the atmospheric pressure is falling.

Times of high atmospheric pressure, when gas emissions from the ground are suppressed, can be associated with wind-less conditions. However, falling and low atmospheric conditions are typically associated with wind.

Atmospheric pressure changes can also influence the water table level (see Section 4.1.5).

4.1.4 Rainfall

Permeation of rainfall can result in a significant decrease in the porosity of the ground by closing or blocking pores in the soil or other ground cover materials, and may temporarily seal the ground surface. As a result gas will be prevented from escaping from the ground surface and other migration pathways, e.g. into the ventilation layer, may be enhanced.

In the UK rainfall is frequently associated with low atmospheric pressure(6). The combined effect of increasing gas release from the source and inhibition of escape to atmosphere through the ground surface would increase the volume of gas that may enter the ventilation layer.

Rainfall is likely to be an important factor in the transport of gas into the ventilation layer only for buildings that are surrounded by a significant amount of soft landscaping or granular hard landscaping.

4.1.5 Water Table

The water regime on site can influence the amount of interchange of gas between the ground and atmosphere[4], or ventilation layer.

Rising water tables can act as a pump displacing gas from the ground. In addition a rising water table can seal horizontal migration pathways and so increase gas escaping to atmosphere via the ground surface or if the ventilation layer is present into the ventilation layer.

Falling water tables will draw atmospheric air into the ground and so dilute the concentration of the soil gases. It will also open up the horizontal gas migration pathways that may exist on site. In such circumstances both the volume of gas entering the ventilation layer may be decreased and the concentrations of such gas may be lower.

4.2 Gas Properties

4.2.1 Gas Density

Gases produced by microbial decay of organic matter consist predominantly of methane and carbon dioxide. The density of the two gases will affect the tendency of the soil gas to form layers within the ventilation layer. Methane which has a density lower than air will tend to rise to the surface of the ventilation layer while carbon dioxide which has a density greater than air will migrate towards the base of the ventilation layer.

For responsive ventilation layers the tendency of soil gas to form layers will not be significant since the rate of flow of air through the layer will be sufficient to maintain mixing of the gases.

Landfill gas is slightly less dense than air and this can be beneficial in dispersing gas through high risers, particularly in conjunction with temperature effects.

5. *Example Gas Regimes Studied*

In CIRIA Report 149[3], it was reported that passive gas protective measures had been used in gas affected ground described as Characteristic Situations 2 to 5 (see Table 1). In the current study the ventilation performance of the different ventilation media were studied for 6 different gas regimes. The 6 gas regimes are based on the range of Characteristic Situations in CIRIA Report 149[3], and are shown in Table 6.

Table 6: Gas Regimes Considered in CFD Modelling

Gas Regime[1]	Hazardous Gas Concentration (%v/v)	Emission Rate[2] ($m^3/m^2/s$)	Equivalent Borehole Flow Velocity[3] (m/s)	Equivalent Characteristic Situation[3]
A[4]	1	0.98×10^{-6}	0.005[5]	2[4]
B	5	0.98×10^{-6}	0.005[5]	3
C	5	1.96×10^{-6}	0.01	4
D	20	0.98×10^{-6}	0.005[5]	4
E	20	1.96×10^{-6}	0.01	4
F	20	9.8×10^{-6}	0.05	5

1 Gas regime defined by both gas concentration and emission rate.
2 Equivalent total gas flow velocity from a 50mm diameter borehole calculated from emission rate using Pecksen[12].
3 After CIRIA Report 149[3]
4 Corresponds to situations where the solutions outlined in BRE 212[1] are acceptable.
5 Detection limit for hot wire anonometer is 0.01m/s. Emission rates of 0.005m/s may register as below detection limit.

Within Table 6 gas emission rates from the ground have been related to the borehole gas flow velocity using the relationship developed by Pecksen[12]. Pecksen assumed that a 50mm diameter borehole has a cylindrical zone of influence of 10m^2 (radius1.78m). Pecksen assumed what he considered to be a low radius of influence, to allow for uncertainties in ground conditions and standpipe installation, so that within the relationship there was a tendency to over estimate the emission rate from the ground. A full discussion on gas flows from borehole standpipes in the ground is given in CIRIA Report151[6].

6. Design Considerations For Ventilation Layer

6.1 Purpose of Layer

The purpose of the ventilation layer is to limit the concentrations of methane, carbon dioxide (and any other hazardous gases) below the gas barrier to an acceptable target concentration and to ensure that only a minimal differential pressure can develop across the gas barrier, such that if a failure occurs in the gas barrier there is no significant increase in the risk to occupants in the building above.

6.2 Available Options

A high permeability ventilation layer can be provided through the use of the following media:

- an open void space;
- proprietary void formers such as expanded polystyrene or geocomposite systems;
- granular blankets consisting of permeable aggregates; and
- granular blankets with perforated pipe or geocomposite drain networks.

6.3 Target Concentration

The target equilibrium concentrations selected for the ventilation layer should be based on a site-specific risk-based assessment, and should consider the following points which are addressed in detail in CIRIA Report 152[8].

- What is the interpreted "gas regime" for the site (see Tables 1 and 6). How complete is the knowledge of the ground conditions? Are the design gas emission rate and assumed soil gas concentrations based on sufficient field measurements? Do they represent the average conditions over the area of the building(s) or an estimated upper bound condition?
- What are the uses and the internal ventilation conditions of the building? How readily could the ventilation be changed, particularly reduced, by human intervention? (Buildings with large rooms and good natural or mechanical ventilation can tolerate a higher equilibrium concentration in the ventilation layer than buildings with small rooms, poor ventilation provisions and sensitive uses.)
- What type of gas membrane will be provided? What inspection and testing will be carried out? What is the risk of defects in the membrane or damage after placement?
- What is the form of construction of the floor slab? What is the potential for cracking or post construction movement?
- Is it necessary for the maximum target equilibrium concentration to be maintained across the whole foundation all of the time or can it be exceeded locally and occasionally? Occasional exceedence of the target concentration over parts of the foundation during calm weather conditions should only be allowed without increasing the consequent risk to an unacceptable level.
- What is the possibility of current and future occupiers blocking some or all side ventilation points?
- What is the possibility of future changes of use to the building that may compromise the ventilation space?

6.3.1 Example Target Equilibrium Concentrations

Target equilibrium concentrations for passive ventilation systems might be set at 1% by volume for methane (1/5 of the Lower Explosive Limit [LEL]) and 1.5% by volume for carbon dioxide for atmospheric conditions prevailing 95% of the time. These are the limiting concentrations inside buildings below which the safety procedures described in Waste Management Paper 27[9] do not need to be initiated.

The acceptable target concentration adopted for passive gas protection systems will be site specific and should take into account the particular circumstances for the development. A higher target concentration may be acceptable for an industrial or retail building with a large interconnected, well ventilated internal space. Lower target concentrations may be considered necessary for domestic housing.

6.4 Ventilation Layer Connections to Atmosphere

The size, type, location and spacing of connections to the atmosphere can have a substantial effect on the ability of ventilation layers to function efficiently. Typical ventilation details are summarised below.

- Side openings direct to a atmosphere, e.g. air bricks, pipe openings with grills, etc.
- External gravel filled pits or trenches connected to the ventilation layer by openings at intervals through the external building walls below ground level.
- Low level pipe risers (periscope vents) connected to the ventilation layer below ground level, either at the edges of the layer or internally.
- Roof level vertical risers with or without ventilation terminals.

Where side vents are used, these are usually placed on (at least) opposite faces of the layer to promote cross ventilation and minimise the risk of dead spots. The same principle applies to below-ground side ventilation via gravel filled pits, trenches or low level periscope vents. Where it is not possible to have side vents on opposite faces of the ventilation layer (e.g. where downstanding walls or deep beams are present) inlet air must be provided by unperforated pipes to the internal closed side of the layer, to create cross ventilation.

For large plan area buildings, where it is not possible or economic to form a void space, high porosity void formers or granular layers with alternatively interleaved perforated pipes or drains have commonly been specified. The types of ventilation layer connection that can be used are dependent on the type of slab construction, the relative levels of the ventilation layer and external ground level, and the type of ventilation layer used.

Ventilation terminals can be used to enhance wind induced up-draught. Testing of various terminals currently available on the market by BRE has shown that:

- terminal performance can vary widely and even visually similar types may behave very differently;
- rotating cowls and H pots generally assist flow better than the other systems tested;
- mushroom caps and Chinese hats may cause flow reversal under certain wind conditions.

While terminals can produce updraught through both pressure and thermal effects, there is a head loss due to the riser pipe. The design of any terminal must therefore carefully consider these conflicting inputs.

The efficiency of a ventilation terminal depends on wind characteristics as well as the terminal design. Wind characteristics (direction, angle, speed) will be influenced by adjoining structures such as roof ridges. Therefore the location of the terminals should be such as to maximise wind - induced updraught, e.g. above eaves level and away from windows.

The practical advantage of high level risers is that the soil gases are vented away from the public, possible ignition sources and are less vulnerable to vandalism. Additionally they are less susceptible to being blocked by, for example, temporary or permanent obstructions, plant growth, etc, which can all effect low level vents. The principal disadvantage of high level risers is that the riser pipes and terminals can be very visible and are often considered to be aesthetically displeasing.

6.5 *Example Limiting Performance Concentrations for Methane*

The performance assessment of the ventilation layer for a particular development should take into account the site specific factors applying. For example for an industrial or retail building with a large interconnected, well ventilated internal space it may well be acceptable to design for higher wind speeds and/or for higher target concentrations

In this research report the gas dispersal performance characteristics of various ventilation media for a methane gas hazard have been defined as follows (also shown graphically in Figure 3.1).

VERY GOOD	The steady state concentration of methane over 100% of the ventilation layer remains below 1% by volume at a wind speed of 0.3m/s.
GOOD	The steady state concentration of methane over 100% of the ventilation layer remains below 1% by volume at a wind speed of 1m/s and below 2.5% by volume (50% LEL) at a wind speed of 0.3m/s.
FAIR	The steady state concentration of methane over 100% of the ventilation layer remains below 1% by volume at wind speed of 2m/s and below 5% by volume (100% LEL) at a wind speed of 0.3m/s.
POOR	The steady state concentration of methane over 100% of the ventilation layer remains below 1% by volume at wind speed of 3m/s and below 5% by volume (100% LEL) at a wind speed of 1m/s.
UNSUITABLE	The steady state concentration of methane over 100% of the ventilation layer is above 1% by volume at a wind speed of 3m/s and above 5% by volume (100% LEL) at a wind speed of 1m/s.

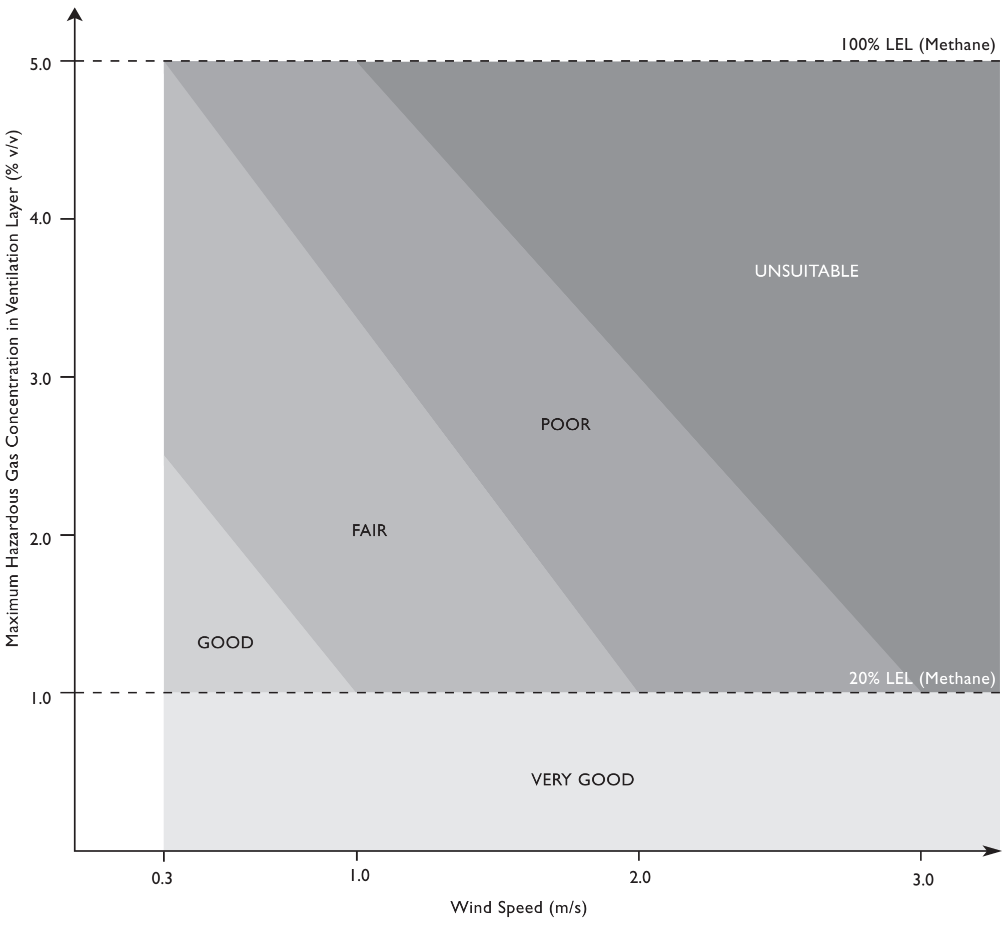


Figure 3.1 Performance Assessment Criteria of Ventilation Layer for Methane Hazard

6.6 *Example Limiting Performance Concentrations for Carbon Dioxide*

The performance assessment of the ventilation layer for a particular development should take into account the site specific factors applying.

An example of a gas dispersal performance characteristic that could be used to assess the performance of a ventilation layer for a carbon dioxide hazard is defined below and is also shown graphically in Figure 3.2.

VERY GOOD	The steady state concentration of carbon dioxide over 100% of the ventilation layer remains below 1.5% by volume at a wind speed of 0.3m/s.
GOOD	The steady state concentration of carbon dioxide over 100% of the ventilation layer remains below 1.5% by volume at a wind speed of 1m/s and below 5% by volume at a wind speed of 0.3m/s.
FAIR	The steady state concentration of carbon dioxide over 100% of the ventilation layer remains below 1.5% by volume at wind speed of 2m/s and below 5% by volume at a wind speed of 1.0m/s.
POOR	The steady state concentration of carbon dioxide over 100% of the ventilation layer remains below 1.5% by volume at wind speed of 3m/s and below 5% by volume at a wind speed of 2m/s.
UNSUITABLE	The steady state concentration of carbon dioxide over 100% of the ventilation layer is above 1.5% by volume at a wind speed of 3m/s and above 5% by volume at a wind speed of 2m/s.

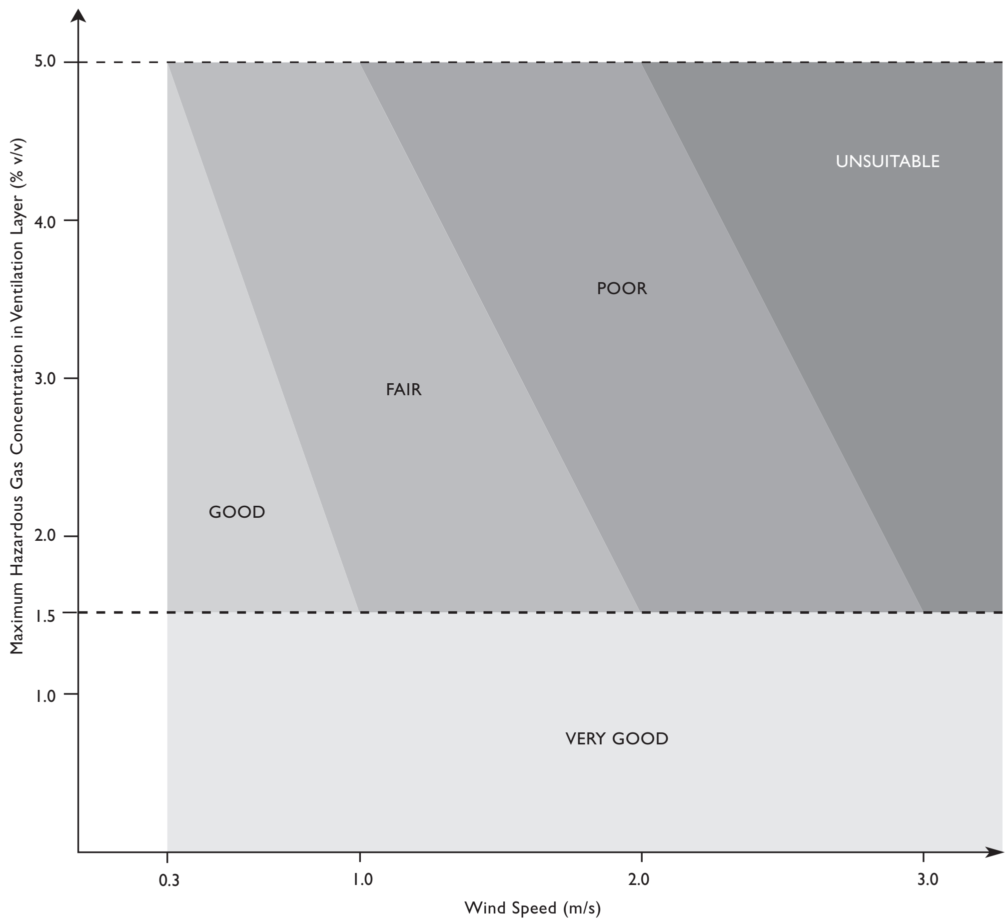


Figure 3.2 Performance Assessment Criteria of Ventilation Layer for Carbon Dioxide

7. *Open Voids*

7.1 *General Considerations*

Provision of an open void space as the ventilation layer requires a suspended floor slab. This may be constructed by use of:

- pre-cast concrete flooring, e.g. block and beam techniques;
- piles, beams and permanent shuttering for slabs.

An open void ventilation layer is generally only economic for small buildings where block and beam techniques can be employed. For medium to large floor area buildings, the cost of permanent shuttering, the larger spans (and correspondingly thicker slabs), the usual increased complexity of the underside of the foundation, and the availability of void forming products, makes this solution unattractive.

The structural, material performance and cost implications associated with open voids are summarised in Table 7

Table 7 Structure Related Considerations in the Application and Use of an Open Void Space Ventilation Layer

Structural or Material Consideration	Suitability	Advantages or Limitations
1. Type of Structure - Ground level - Split level - Full basement	Ground level	Not suitable for split level or full basement buildings.
2. Width[(a)] of Structure - Small - Medium - Large	Small Medium Large	For a open void space to be practical and effective beneath medium and large width structures, the foundation system must be simple and sympathetic [(b)].
3. Slab Design - Ground bearing - Suspended	Suspended slab only	Ground bearing slab design precludes the use of a clear void space ventilation layer. For suspended slabs, a clear void space layer can be economically formed using precast beams and panels; otherwise expensive permanent metal shutting is required. Precast beams and panel construction provides less resistance to upward gas flow by comparison to in-situ concrete slab construction. Therefore there is greater reliance on the integrity and continuity of the membrane, and the gas dispersal properties of the underlying void space.
4. Foundation complexity - Simple[(b)] (sympathetic) - Complex (with multiple obstructions and/or changes of level)	Simple only	Where internal ground beams are present, pipe or vent box openings must be provided at regular intervals, to ensure continuity of the void. As a guide, the area of internal openings should be at least double, and preferably 4 or 5 times the area of perimeter openings on each side of the building.
5. Membrane location - Below slab - Above slab	Above slab	Where precast beams and panels are used, the membrane can only be located above the precast units, and must be overlain by a loading screed. Where heavy internal floor loads or fixings are required, an upper slab may be necessary to protect the membrane.
6. Membrane installation - Compatibility - Regulation/Separation layer - Handleability, Sequencing	Not usually required	Membrane almost always placed above precast units/structural slab on a grout or screed finish.
7. Subgrade preparation	No special measures required	
8. Effects of ground settlement	Unaffected	
9. Other Issues: (i) Thickness (ii) Post-construction monitoring (iii) Conversion to active system		 (i) 100mm layer is sufficient. (ii) Can be readily monitored during or after construction (if deemed necessary). (iii) Retrofitting of forced system easy.

Structural or Material Consideration Notes

(a) Width of structure is the dimension between the opposite sides of the building on which ventilation points are sited. Small means less than about 7.5m, Medium means between about 7.5m and 15m, Large means wider than about 15m.

(b) Sympathetic means that the underside of the foundation is flat (or slopes up towards the edges of the building) and has a minimum of obstructions (ground beams, pilecaps, partition walls, etc).

7.2 *Results of CFD Simulations*

The results of the modelling for open voids, are presented numerically in Tables 8, 9 and 10. The volume flow rates of air through a 200mm open void is compared to other media on Figures 4 and 5. The results of modelling of a 5m x 5m and a 30m wide foundation, both with a 200mm open void are shown graphically on Figures 6 and 7 respectively.

The CFD simulations show that:

- open voids are the most efficient media for the dispersal of soil gas emissions;
- the ventilation performance of open voids is sensitive to the amount of open area of side ventilation. For a 30m wide foundation, doubling the side ventilation produced a 45% reduction in the maximum steady state hazardous gas concentration; and
- the ventilation performance of open voids is not sensitive to the depth of the void, over the range considered.

Table 8 Results of CFD Modelling of Open Void Ventilation Layers : Volume Flow Rates of Air

Foundation Size (m)	Void Depth (mm)	Side Ventilation(1) (mm²/m)	Volume Flow Rate of Air Through Ventilation Layer (m^3/m width/h)			Volume Flow Rate of Gas into Ventilation Layer (m^3/m width/h)	
			Wind Speed 3m/s	Wind Speed 1m/s	Wind Speed 0.3m/s	Gas Emission Rate 0.05m/s	Gas Emission Rate 0.01m/s
5x5	200	2652	12.17	4.04	1.20	0.18	0.035
	400	2652	-	-	1.26	0.18	0.035
30 wide	200	2210	10.58	3.45	0.95	1.06	0.21
	200	4420	-	-	2.02	1.06	0.21
	400	2210	-	-	0.96	1.06	0.21

(1) on each of 2 opposite sides only

Table 9 Results of CFD Modelling of an Open Void Ventilation Layer Beneath a 5m x 5m Foundation: Maximum Gas Concentrations

Gas Regime	Void Depth (mm)	Side Ventilation(1) (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	200	2652	0.002	0.005	0.014
	400	2652	0.002	0.004	0.012
B	200	2652	0.01	0.02	0.07
	400	2652	0.01	0.02	0.06
C	200	2652	0.02	0.05	0.14
	400	2652	0.02	0.04	0.12
D	200	2652	0.04	0.09	0.27
	400	2652	0.03	0.08	0.24
E	200	2652	0.07	0.18	0.55
	400	2652	0.06	0.17	0.47
F	200	2652	0.35	0.91	2.74
	400	2652	0.30	0.84	2.37

(1) on each of 2 opposite sides only

Table 10 Results of CFD Modelling of an Open Void Ventilation Layer Beneath a 30m Wide Foundation: Maximum Gas Concentrations

Gas Regime	Void Depth (mm)	Side Ventilation[1] (mm^2/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	200	1473	-	-	0.11
	200	2210	0.01	0.03	0.09
	200	4420	-	-	0.05
	400	2210	0.01	0.01	0.08
B	200	1473	-	-	0.56
	200	2210	0.05	0.15	0.44
	200	4420	-	-	0.24
	400	2210	0.05	0.07	0.41
C	200	1473	-	-	1.13
	200	2210	0.10	0.29	0.88
	200	4420	-	-	0.48
	400	2210	0.10	0.14	0.82
D	200	1473	-	-	2.26
	200	2210	0.20	0.58	1.77
	200	4420	-	-	0.96
	400	2210	0.20	0.27	1.64
E	200	1473	-	-	4.52
	200	2210	0.40	1.16	3.53
	200	4420	-	-	1.91
	400	2210	0.40	0.54	3.28
F	200	1473	-	-	20
	200	2210	1.99	5.82	17.66
	200	4420	-	-	9.57
	400	2210	1.98	2.70	16.42

[1] on each of 2 opposite sides only

(shaded) UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1).

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with a 200mm deep void are shown in Figures A2.1 to A2.3 in Volume 2.

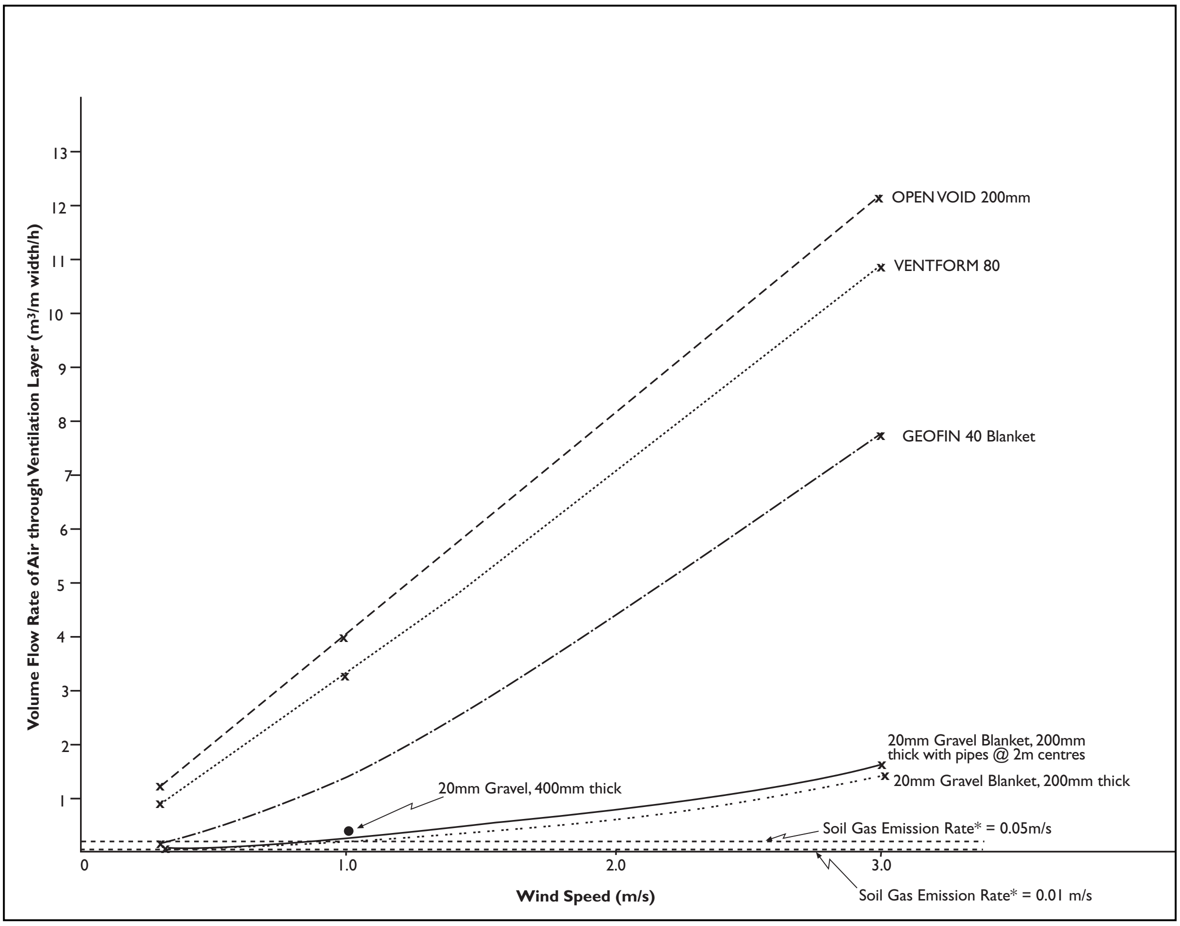


Figure 4
Result of CFD Modelling: Volume Flow Rate vs Wind Speed for 5m x 5m Foundation

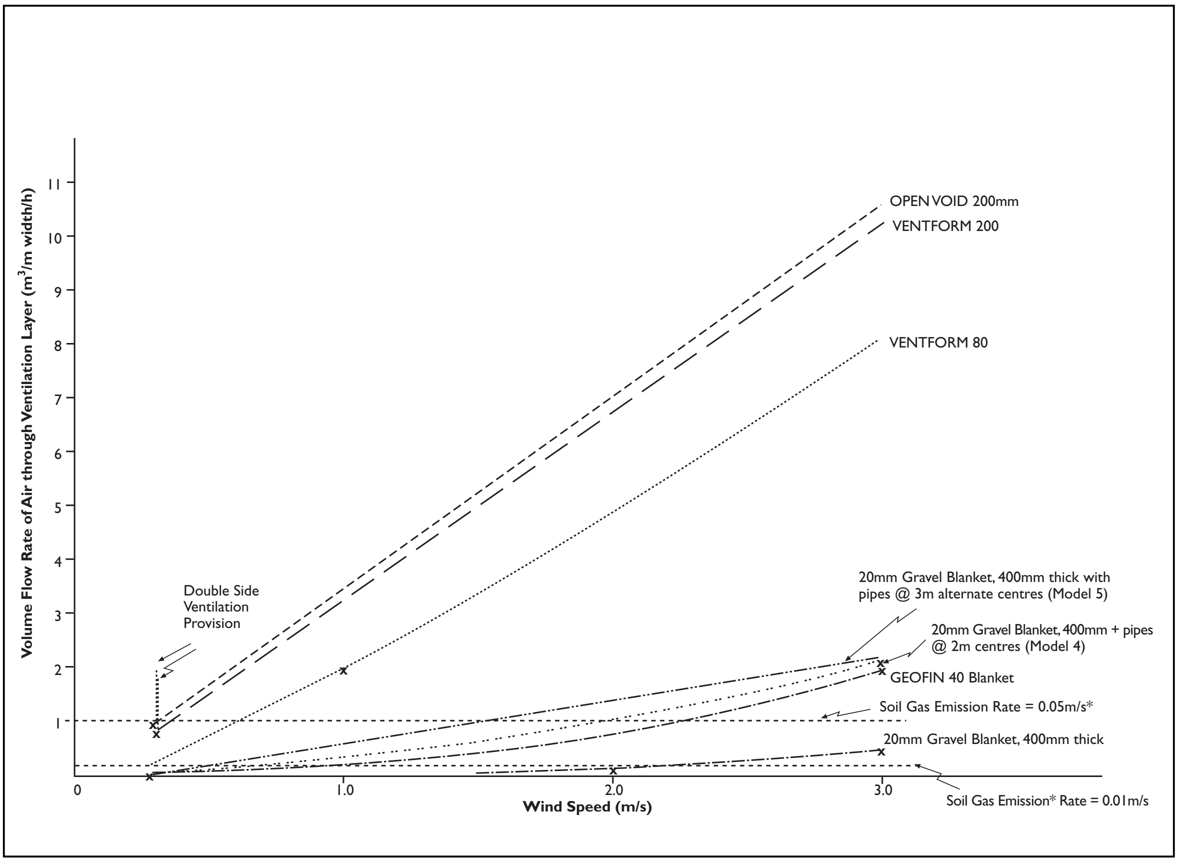


Figure 5
Result of CFD Modelling: Volume Flow Rate vs Wind Speed for 30m Wide Foundation

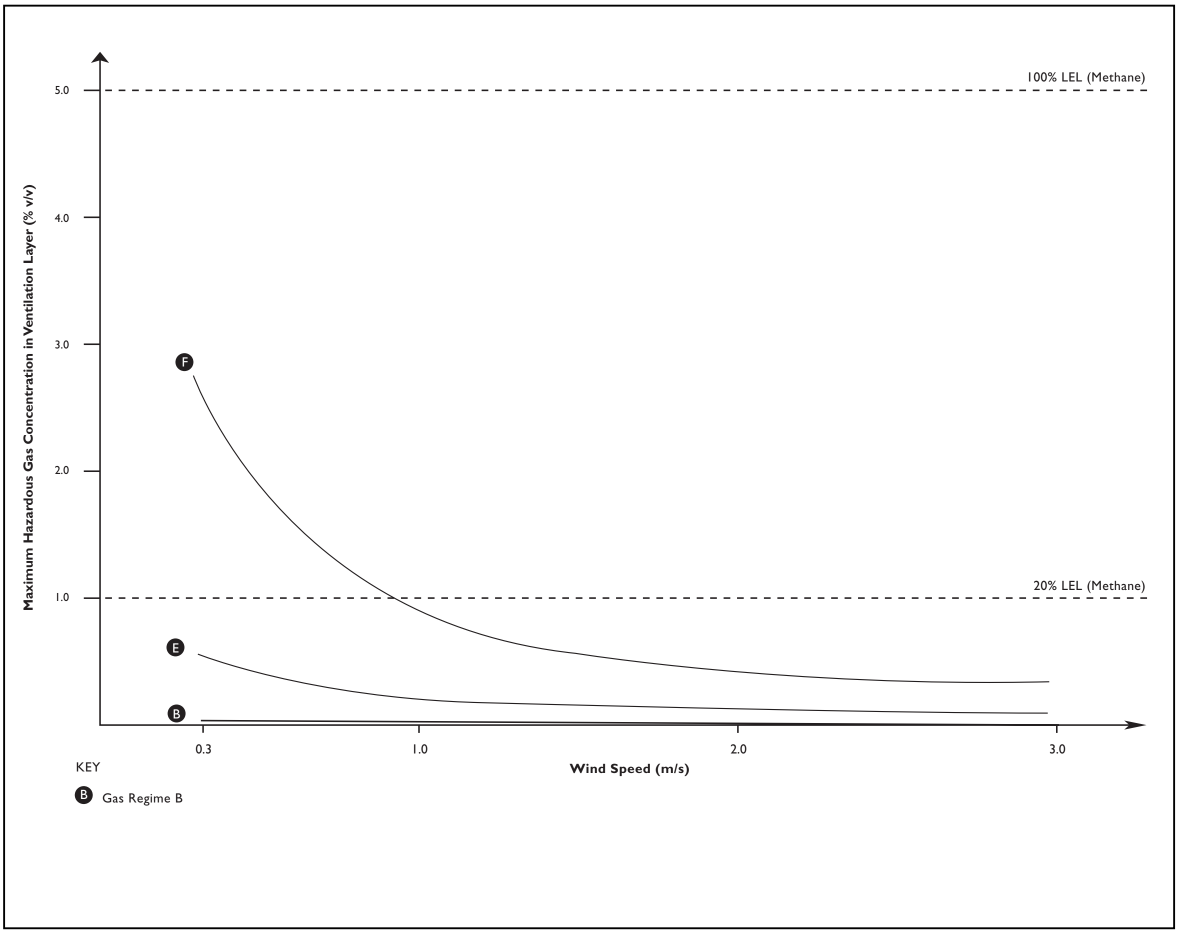


Figure 6
Plot of Wind Speed vs Maximum Concentration: 5m x 5m Foundation, Open Void 200mm deep

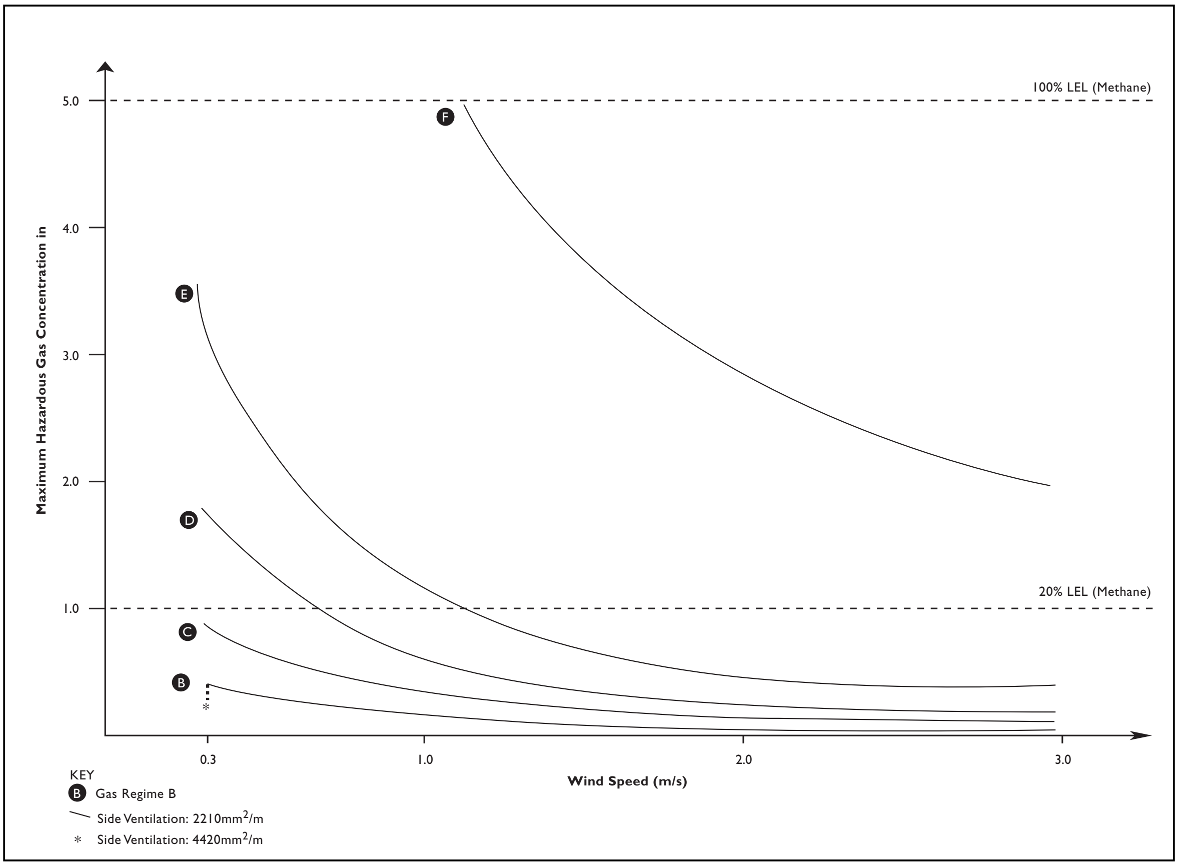


Figure 7
Plot of Wind Speed vs Maximum Concentration: 30m Wide Foundation, Open Void 200mm deep

7.3 *Conclusions Regarding Use of Open Void Ventilation Layer*

As a result of the CFD modelling carried out on open voids, it is considered that:

- open voids are suitable for sites up to and including Gas Regime E;
- open voids may be suitable for sites falling within Gas Regime F, depending on the width and complexity of the foundation, the design soil gas emission rate, target equilibrium concentration, and the sensitivity of the building's use;
- the depth of an open void ventilation layer should not be less than 100mm (this is based on constructional considerations as well as ventilation performance);
- side ventilation must be provided on at least 2 opposite sides of the ventilation layer, and preferably on all sides;
- for small to medium width buildings (up to about 15m width) buildings the minimum area of side ventilation should be 1500mm^2/m run of wall for gassing regimes up to and including Gas Regime E;
- for larger width buildings the minimum area of side ventilation should be:

  - 2000mm^2/m run of wall for gas regimes up to and including Gas Regime C and

  - 4500mm^2/m run of wall for Gas Regimes D and E
- where the internal void space is interrupted with downstanding beams etc., the area of the openings in the beams should be a minimum of double the area of the side ventilation and preferably 4 or 5 times the area.

8. Expanded Polystyrene Shuttering

8.1 General Considerations

Expanded polystyrene shuttering is available in two general forms - with square legs and with round legs.

The volume of void produced by expanded polystyrene shuttering systems (for a given foundation area) is governed by:

- the shape of the leg;
- the leg depth;
- the spacing of the legs; and
- type of substrate upon which the system is bedded.

In general, round leg shuttering products produce a larger void volume than the square leg shuttering products, because the round legs have a greater leg depth and are also spaced further apart. The square leg shuttering produces a small equivalent clear void depth (22mm or 33 mm) and is intended to be used where ground bearing capacity is required.

The load carrying capacity of the expanded polystyrene shuttering is determined by the density of the polystyrene material and the bearing area of the legs of the shuttering. In the VENTFORM product range the square leg shuttering has a bearing area of 44%, while the round leg shuttering has a bearing area of 19%. Square leg shuttering is available to support loads of up to 50kN/m^2.

The structural, material performance and cost implications associated with expanded polystyrene shuttering are summarised in Table 11 overleaf.

Table 11: Structure Related Considerations in the Application and Use of an Expanded Polystyrene Shuttering System

Structural or Material Consideration	Suitability	Advantage or Limitations
1. Type of Structure - Ground level - Split level - Full basement	All types	Effective means of linking blankets at different levels required (where split levels or basements occur). Panels can be installed horizontally and vertically to achieve continuity of void.
2. Width[(a)] of Structure - Small - Medium - Large	All widths	Well suited to medium and large width buildings, due to a combination of high gas transmissivity characteristics (compared to alternative media) and maximisation of standard size (1.2m x 1.2m) panels.
3. Slab Design - Ground bearing - Suspended	Both ground bearing and suspended slabs	Square leg expanded polystyrene used for ground bearing slabs with load bearing capacities of $20kN/m^2$ to $50kN/m^2$ depending on density. Round leg expanded polystyrene used for suspended slab foundations.
4. Foundation complexity - Simple[(b)] (sympathetic) - Complex (with multiple obstructions and/or changes of level)	Simple Complex	Polystyrene shuttering can readily be cut on site to match sympathetic[(b)] foundation layouts. Complex arrangements require much more site cutting of the standard panels, use of special prefabricated components (eg pile collars), and provision of pipe or ventbox openings through internal ground beams. Changes in slab level across the foundation area are more difficult to accommodate than beam and pilecap obstructions.
5. Membrane location - Below slab - Above slab	Polystyrene shuttering designed for below slab membrane installation	Membrane is laid directly on polystyrene shuttering.
6. Membrane installation - Compatibility - Regulation/Separation layer - Handleability - Sequencing	Very suitable system	Provides clean level surface on which membrane can be laid, jointed and sealed. No separation layer required. Provides good stable surface for following trades. Absorbs local impact and thereby reduces risk of post-installation impact damage.
7. Subgrade preparation	Strict level and strength requirements	A firm, levelled subgrade surface must be prepared. This is usually topped with a thin sand blinding layer. Any penetration of the legs of the shuttering into the blinding layer (and subgrade) will reduce the gas dispersal performance of the polystyrene shuttering layer
8. Effects of ground settlement	Not particularly sensitive to ground settlement.	If large settlements are expected lightweight panels are easily secured to underside of membrane with self adhesive patches. Membrane bonded to slab with proprietary fixing during concreting.
9. Other Issues: (i) Handling (ii) Edge fixing (iii) Durability (iv) Thermal insulation (v) Post-construction monitoring (vi) Conversion to active system	(i) Easily handled. No heavy equipment required. (i) Good perimeter venting. (iii) Durable under typical conditions. (iv) Good thermal insulation. (v) Can be readily monitored. (vi) Can retrofit active system	(i) Panels are light and easy to handle. Fast and simple to lay, including site cutting. (ii) Continuous 2-way void provides good ventilation to edge air in/extract points and to ducts through internal downstands. Care needed in cutting panels adjacent to vent points to ensure legs do not locally impede flow. (iii) If shuttering to be laid in particularly chemically aggressive conditions, review durability to specific hazards. (iv) Thermal insulation value of $0.45\ W/m^2/oC$ or better. (v) Monitoring system should be installed at time expanded polystyrene panels are laid.

Structural or Material Consideration Notes

(a) Width of structure is the dimension between the opposite sides of the building on which ventilation points are sited. Small means less than about 7.5m; Medium means between about 7.5m and 15m; Large means wider than about 15m

(b) Sympathetic means that the underside of the foundation is flat (or slopes up towards the edges of the building) and has a minimum of obstructions (ground beams, pilecaps, partition walls, etc)

8.2 *Results of CFD Modelling*

The results of the modelling for different expanded polystyrene shuttering systems are presented numerically in Tables 12, 13, and 14. The results of modelling a 5m x 5m and 30m wide foundation with an expanded polystyrene shuttering system with an equivalent depth of clear void of 22mm and 100mm are shown on Figures 8 and 9. The volume flow rate of air through expanded polystyrene shuttering systems with an equivalent depth of clear void of 22mm and 100mm is compared to other media on Figures 4 and 5.

The CFD simulations have shown that:

- expanded polystyrene shuttering is an effective media for the dilution and dispersal of gas beneath buildings, performing almost as well as an open void space of similar depth;
- the ventilation performance of expanded polystyrene is not particularly sensitive to depth for smaller foundations sizes and at higher wind speeds (>3m/s). However, on larger foundation sizes at lower wind speed (<1m/s), increasing the depth of the shuttering produces a significant improvement in the ventilation performance of the layer.
- the ventilation performance of expanded polystyrene shuttering is sensitive to the open area of side ventilation. For a 30m wide foundation, doubling the side ventilation produced a 45% reduction in the maximum steady state hazardous concentration.

Table 12: Results of CFD Modelling of Expanded Polystyrene Shuttering Systems: Volume Flow Rate of Air through Layers

Foundation Size (m)	Equiv. Depth of Clear Void (mm)	Side Ventilation[(1)] (mm^2/m mm wall)	Volume Flow Rate of Air Through Ventilation Layer (m^3/m width/h)			Volume Flow Rate of Gas into Ventilation Layer (m^3/m width/h)	
			Wind Speed 3m/s	Wind Speed 1m/s	Wind Speed 0.3m/s	Gas Emission Rate 0.05m/s	Gas Emission Rate 0.01m/s
5x5	22	2652	10.92	3.40	0.86	0.18	0.035
	33	2652	11.43	3.68	1.04	0.18	0.035
	60	2652	-	-	1.17	0.18	0.035
	100	2652	-	-	1.2	0.18	0.035
30 wide	22	2210	8.07	1.98	0.22	1.06	0.21
	33	2210	8.92	2.53	0.45	1.06	0.21
	60	2210	9.86	-	0.50	1.06	0.21
	100	2210	10.21	-	0.84	1.06	0.21
	100	4420	-	-	1.79	1.06	0.21

(1) on each of 2 opposite sides only

Table 13: Results of CFD Modelling for Expanded Polystyrene Shuttering Beneath a 5m x 5m Foundation: Maximum Gas Concentrations

Gas Regime	Equivalent Depth of Clear Void (mm)	Side Ventilation[1] (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	22	2652	0.003	0.007	0.026
	33	2652	0.003	0.007	0.022
	60	2652	-	-	0.021
	100	2652	-	-	0.02
B	22	2652	0.01	0.04	0.13
	33	2652	0.01	0.03	0.11
	60	2652	-	-	0.10
	100	2652	-	-	0.10
C	22	2652	0.03	0.07	0.26
	33	2652	0.03	0.07	0.22
	60	2652	-	-	0.21
	100	2652	-	-	0.20
D	22	2652	0.05	0.15	0.53
	33	2652	0.05	0.14	0.44
	60	2652	-	-	0.41
	100	2652	-	-	0.40
E	22	2652	0.01	0.29	1.06
	33	2652	0.01	0.27	0.89
	60	2652	-	-	0.83
	100	2652	-	-	0.79
F	22	2652	0.51	1.45	5.29
	33	2652	0.52	1.35	4.43
	60	2652	-	-	4.14
	100	2652	-	-	3.97

(1) on each of 2 opposite sides only

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 5 mx 5m foundation with expanded polystyrene shuttering (equivalent clear depth of 22mm) are shown in Figures A3.1 to A3.3 in Volume 2.

Table 14: Results of CFD Modelling for Expanded Polystyrene Shuttering Beneath a 30m Wide Foundation: Maximum Gas Concentrations

Gas Regime	Equivalent Depth of Clear Void Depth (mm)	Side Ventilation[1] (mm^2/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	22	2210	0.01	0.05	0.28
	33	2210	0.01	0.04	0.17
	60	2210	0.01	-	0.11
	100	736	-	-	0.28
	100	2210	0.01	-	0.10
	100	4420	0.01	0.01	0.06
B	22	2210	0.07	0.25	1.25
	33	2210	0.06	0.20	0.83
	60	2210	0.06	-	0.54
	100	736	-	-	1.40
	100	2210	0.06	-	0.50
	100	4420	-	-	0.28
C	22	2210	0.14	0.52	2.84
	33	2210	0.12	0.41	1.66
	60	2210	0.12	-	1.09
	100	736	-	-	2.79
	100	2210	0.11	-	1.00
	100	4420	-	-	0.55
D	22	2210	0.27	1.02	4.99
	33	2210	0.25	0.81	3.31
	60	2210	0.24	-	2.18
	100	736	-	-	5.58
	100	2210	0.23	-	2.00
	100	4420	-	-	1.10
E	22	2210	0.55	2.03	9.98
	33	2210	0.49	1.62	6.63
	60	2210	0.47	-	4.36
	100	736	-	-	11.16
	100	2210	0.45	-	4.00
	100	4420	-	-	2.21
F	22	2210	2.73	10.15	20
	33	2210	2.47	8.10	20
	60	2210	2.35	-	20
	100	736	-	-	20
	100	2210	2.27	-	20
	100	4420	-	-	11.04

[1] on each of 2 opposite sides only

(shaded cells) UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with expanded polystyrene shuttering (equivalent clear depth of 60mm) are shown in Figures A4.1 to A4.3 in Volume 2.

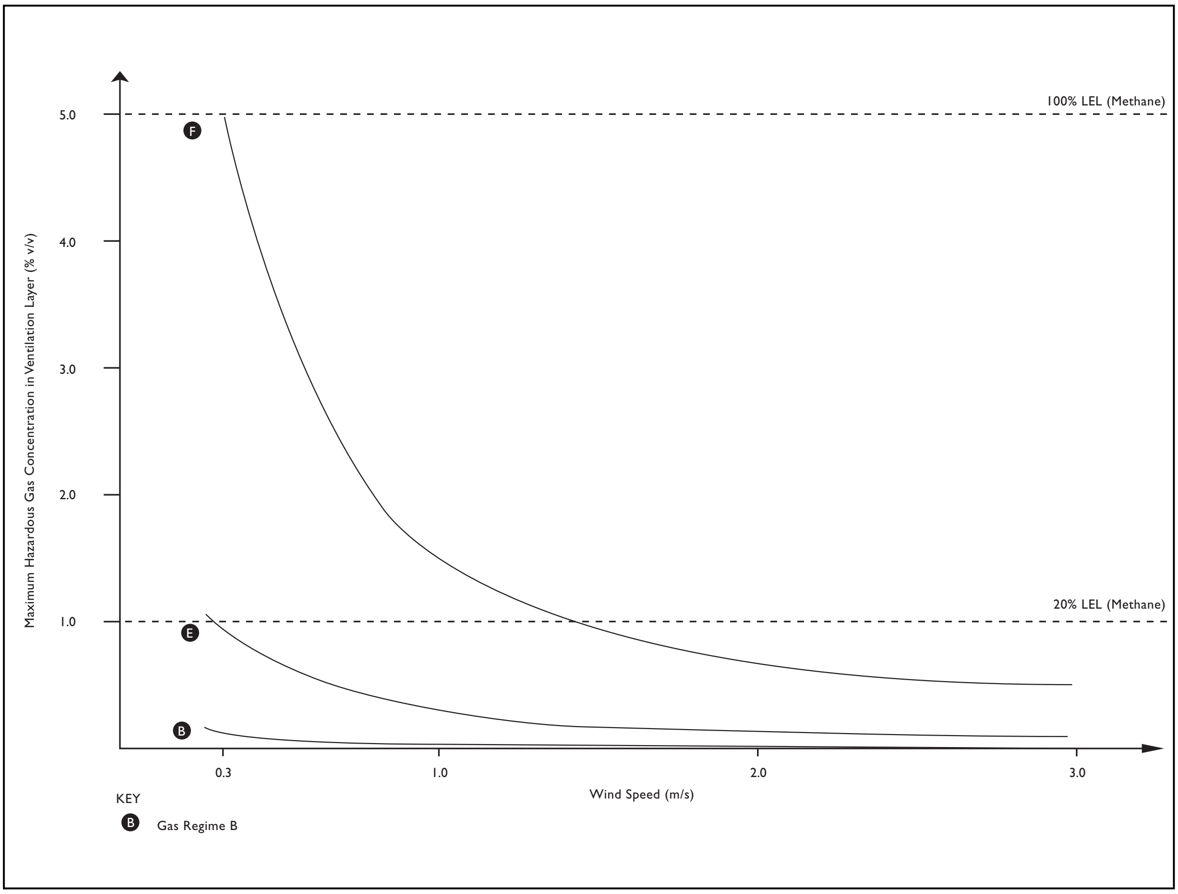


Figure 8
Plot of Wind Speed vs Maximum Concentration: 5m x 5m Foundation, Ventform 80

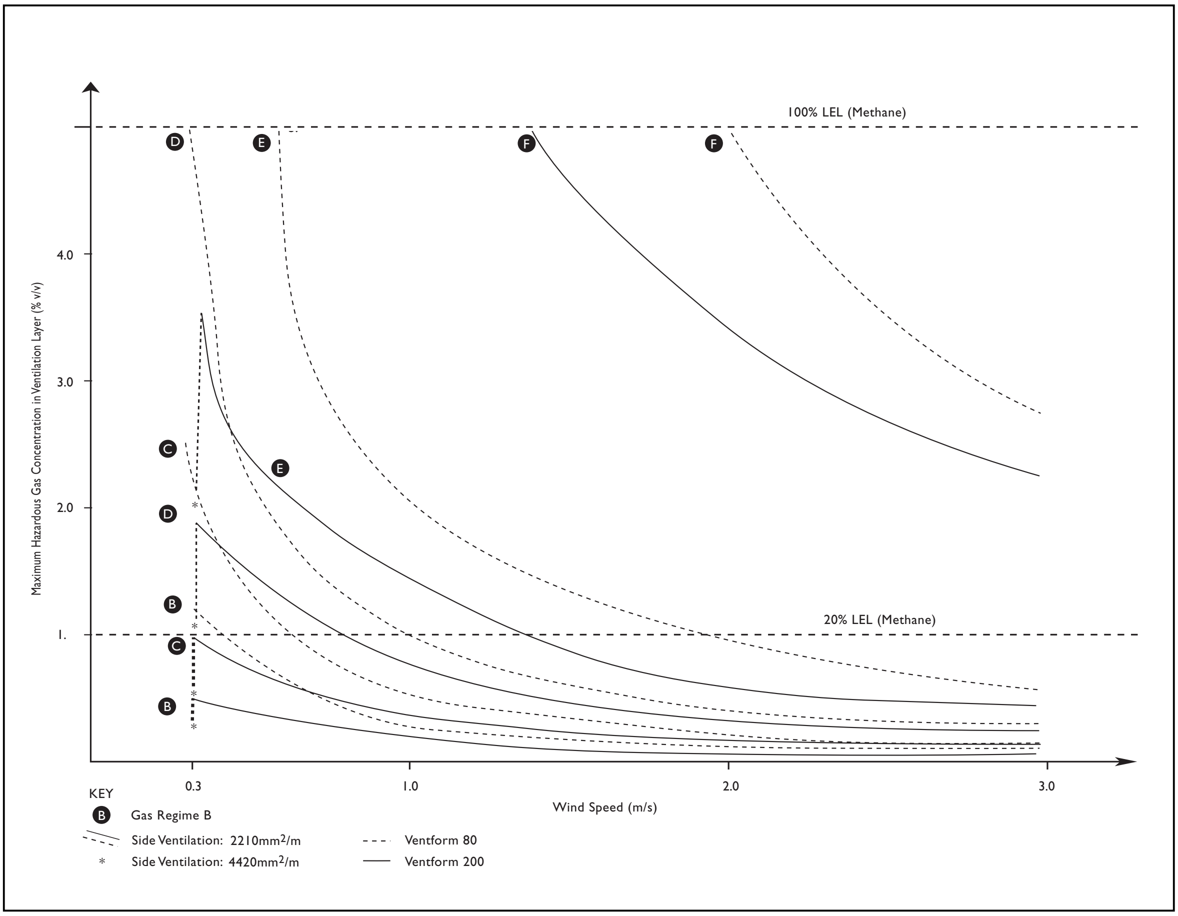


Figure 9
Plot of Wind Speed vs Maximum Concentration: 30m Wide Foundation, Ventform 80 and 200

8.3 *Conclusions Regarding the Use of Expanded Polystyrene Shuttering*

As a result of the modelling of various sizes and shapes of expanded polystyrene shuttering it is considered that:

- expanded polystyrene shuttering with an equivalent depth of clear void of 22mm is suitable for small width (up to about 7.5m) buildings for sites up to and including Gas Regime E;
- expanded polystyrene shuttering with an equivalent depth of clear void of 100mm is suitable for large width (30m) buildings for sites up to and including Gas Regime E;
- for small width buildings the minimum area of ventilation is 1500mm^2/m run of wall for sites up to and including Gas Regime E;
- for large width buildings the minimum area of side ventilation is :

  - 2000mm^2/m run of wall for sites up to and including Gas Regime C;

  - 4500mm^2/m run of wall for Gas Regimes D and E;
- for complex foundations, particularly those on medium to large width buildings, the open area/m width through downstanding beams etc must be several times the open area/m width of the side vents, to limit their effect. As the number of obstructions increases, the greater should be the provision for cross ventilation.

9.0 Geocomposite Drainage Blankets

9.1 General Considerations

Geocomposite drainage materials consist of a geotextile filter wrap (e.g. non-woven needle punched polypropylene) and a synthetic polymer core. They are produced as either single or double sided materials.

For use in passive gas protection systems, the following properties are important:

- geotextile
  - permeability
  - pore opening size
  - tensile strength and elongation
  - puncture resistance
- core
  - in plane (horizontal) permeability to gases
  - crush strength
  - shear strength
  - long term creep resistance
  - node orientation (double or single cuspations)
  - flexibility.

The performance of a geocomposite drain is dependent on both the properties of its individual components, e.g. the geotextile wrap and the core, and how they are formed, combined and tested. Clause 514 of the Department of Transport (DoT) Manual of Contract Document for Highway Works (MCDHW) contains a specification for fin drains (geocomposites) and gives consideration to validity of test methods, traceability of raw materials and quality control.

The crush resistance and load carrying capacity of the geocomposite core allows it to directly support ground slabs. It can therefore, be used with both suspended and ground bearing slab construction techniques.

The structural, material performance and cost implications associated with geocomposite drainage blanket materials are summarised in Table 15 overleaf.

Table 15: Structure Related Considerations in the Application and Use of a 40mm Double Sided Geocomposite Drainage Blanket Ventilation Layer

Structural or Material Consideration	Suitability	Advantages or Limitations
1. Type of Structure - Ground level - Split level - Full basement	All types	Blanket can be installed horizontally and vertically. Perpendicular junctions can be formed by either proprietary connectors or by folding the geocomposite, where appropriate.
2. Width[(a)] of Structure - Small - Medium - Large	All sizes, but most suited to small width structures if concentrations and emission rates of methane are appreciable.	Use of a 40mm double sided geocomposite blanket beneath medium and large width buildings should be restricted to gassing regimes defined as Characteristic Situations 3 or less in Table 28 of CIRIA Report 149.
3. Slab Design - Ground bearing - Suspended	Both ground bearing and suspended slabs.	40mm double sided geocomposite can be used beneath imposed loads of 400 kN/m^2, however as the imposed load increases indentation occurs, which reduces the effective open depth of the layer. At loads of up to 200 kN/m^2 negligible indentation occurs.
4. Foundation complexity - Simple[(b)] (sympathetic) - Complex (with multiple obstructions and/or changes of level)	Simple Complex	Geocomposites are able to accommodate complex foundation designs. The double sided symmetrical design of the geocomposite core enables multiaxial installation without loss of cross section. The system may be cut and sealed around physical penetrations, or connected by geocomposite strip, pipe or vent box through internal ground beams.
5 Membrane location - Below slab - Above slab	Either above or below slab.	Membrane can be laid directly on the geocomposites.
6. Membrane installation - Compatibility - Regulation/Separation layer - Handleability - Sequencing	Good compatibility	Membrane may be laid directly on the geocomposite blanket. Geocomposites are robust and special handling is not necessary during installation. In blanket or strip form, geocomposites can be cut to length to suit construction. A range of lap on and jointing details facilitate sequential installation. Fully-wrapped geocomposites do not generally require protection from the following trades for either membrane installation, or slab construction (where membrane is above slab).
7. Subgrade preparation	Requires levelling/regulation layer	Geocomposites must be laid on a reasonably even surface or a granular regulation layer.
8. Effects of ground settlement	Not adversely affected	If large settlements occur beneath suspended slabs, double sided geocomposites such as GEOFIN vent any void space arising beneath the membrane through the geocomposite's "upper layer", thereby ensuring that unventilated gas pockets do not occur.
9. Other Issues: (i) Handling (ii) Thickness (iii) Durability (iv) Post-construction monitoring (v) Conversion to active system	(i) Easily handled. (ii) Slender by comparison with other alternatives. (iii) Good durability under usual conditions. (iv) Proprietry monitoring systems (v) Retrofitting possible	(i) No heavy equipment required. (ii) Excavation of subgrade minimised. (iii) If particularly chemically aggresive conditions will exist, review durability to specific hazards. (iv) Must be inbuilt to the geocomposite. (v) Facilitated through edge collector pipes.

Structural or Material Consideration Notes

(a) Width of structure is the dimension between the opposite sides of the building on which ventilation points are sited. Small means less than about 7.5m; Medium means between about 7.5m and 15m; Large means wider than about 15m

(b) Sympathetic means that the underside of the foundation is flat (or slopes up towards the edges of the building) and has a minimum of obstructions (ground beams, pilecaps, partition walls, etc)

9.2 *Results of CFD Modelling*

CFD simulations were carried out on a 40mm double side geocomposite blanket. The results of the modelling are presented numerically in Tables 16, 17 and 18. The volume flow rate of air through a 40mm double side geocomposite is compared to other media studied on Figures 4 and 5. The results of the modelling of a 5m x 5m and a 30m wide foundation with a 40mm double sided geocomposite are shown graphically on Figure 10 and 11. The modelling showed that:

- a 40mm geocomposite blanket is an effective media for the dispersal of gas for small width foundations on all gas regimes studied, or for large width foundations on very low gas emission rate sites;
- at average wind speeds very little hazardous gas enters the top half of the double sided geocomposite. At lower wind speeds there is very little difference in the gas concentrations in the two halves of the geocomposite;
- the majority (>60%) of the pressure drop occurs within the geocomposite blanket. Within the blanket the pressure drop occurs across the entire width of the blanket;
- the ventilation performance of a 40mm geocomposite blankets is insensitive to the amount of side ventilation provided.

Table 16: Results of CFD Modelling of 40mm Double Sided Geocomposite Blanket: Volume Flow Rates of Air

Foundation Size (m)	Ventilation[1] (mm^2/m)	Volume Flow Rate of Air Through Ventilation Layer (m^3/m width/h)			Volume Flow Rate of Gas into Ventilation Layer (m^3/m width/h)	
		Wind Speed 3m/s	Wind Speed 1m/s	Wind Speed 0.3m/s	Gas Emission Rate 0.05m/s	Gas Emission Rate 0.01m/s
5x5	2652	7.76	1.34	0.12	0.18	0.035
30 wide	2210	1.94	0.18	0.06	1.06	0.21
	4420	-	0.18	-	1.06	0.21

[1] on each of 2 opposite sides only

Table 17: Results of CFD Modelling for 40mm Double Sided Geofin Blanket Beneath 5m x 5m Foundation: Maximum Gas Concentration.

Gas Regime	Layer	Side Ventilation (mm^2/m run wall)(1)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	Top	2652	0	0.002	0.080
	Bottom	2652	0.005	0.026	0.159
B	Top	2652	0.002	0.01	0.40
	Bottom	2652	0.02	0.13	0.80
C	Top	2652	0.004	0.02	0.08
	Bottom	2652	0.05	0.26	1.59
D	Top	2652	0.01	0.04	1.59
	Bottom	2652	0.1	0.53	3.18
E	Top	2652	0.02	0.09	3.18
	Bottom	2652	0.2	1.05	6.36
F	Top	2652	0.08	0.44	15.90
	Bottom	2652	0.99	5.26	20

(1) on each of 2 opposite sides only

(shaded) UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5 Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 5m x 5m foundation with a 40mm double sided geocomposite blanket are shown in Figures A5.1 to A5.6 in Volume 2

Table 18: Results of CFD Modelling for 40mm Double Sided Geocomposite Blanket Beneath 30m Wide Foundation : Maximum Gas Concentrations

Gas Regime	Layer (mm)	Side Ventilation(1) (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
			Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	Top	2210	0.02	0.25	0.5
	Bottom		0.07	0.30	0.5
	Top	4420	-	0.25	-
B	Top	2210	0.09	1.25	2.5
	Bottom		0.36	1.49	2.5
	Top	4420	-	1.24	-
C	Top	2210	0.18	2.49	5
	Bottom		0.71	2.99	5
	Top	4420	-	2.48	-
D	Top	2210	0.36	4.98	10
	Bottom		1.43	5.98	10
	Top	4420	-	4.97	-
E	Top	2210	0.71	9.96	20
	Bottom		2.86	11.95	20
	Top	4420	-	9.94	-
F	Top	2210	3.57	20	20
	Bottom		14.28	20	20
	Top	4420	-	20	-

(1) on each of 2 opposite sides only

[shaded] UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5 Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with a 40mm double sided geocomposite blanket are shown in Figures A6.1 to A6.6 in Volumes 2.

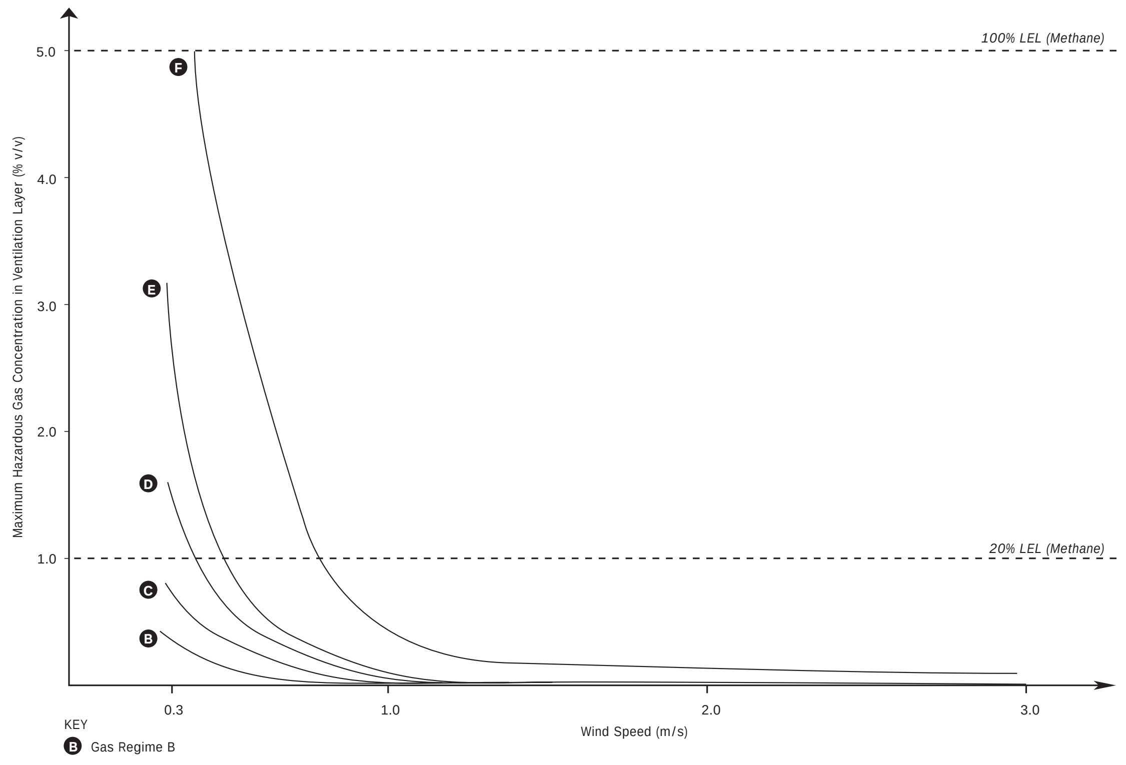


Figure 10
Plot of Wind Speed vs Maximum Concentration: 5m x 5m Foundation, GEOFIN 40 Top Layer

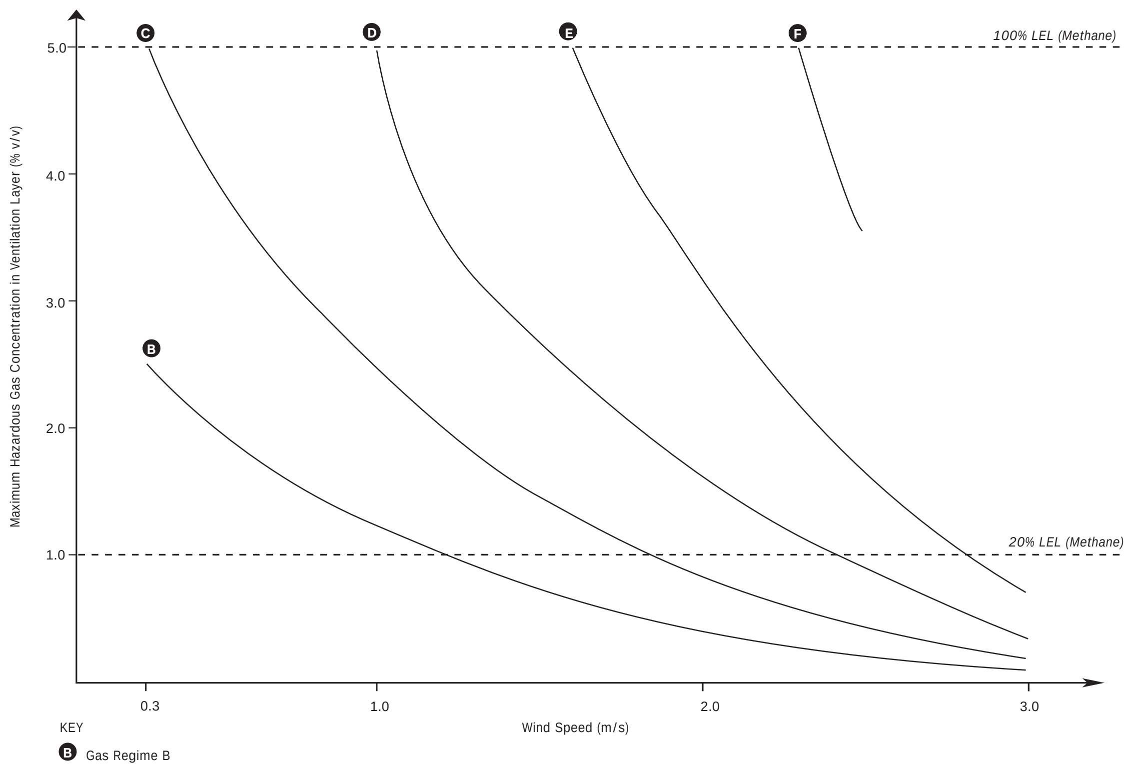


Figure 11
Plot of Wind Speed vs Maximum Concentration: 30m Wide Foundation, GEOFIN 40 Top Layer

9.3 *Conclusions Regarding the Use of Geocomposite Drainage Blanket*

In view of the CFD simulations carried out for geocomposite blankets it is considered that:

- a 40mm double sided geocomposite blanket is suitable for small (up to about 7.5m) width buildings for sites up to and including Gas Regime E;
- a 40mm double sided geocomposite blanket is suitable for large (30m) width buildings for sites up to and including Gas Regime B;
- the minimum area of side ventilation is 1500mm^2/m run of wall for small width buildings and 2000mm^2/m run of wall for large buildings.

10. Granular Blankets

10.1 General Considerations

One method of constructing a ventilation layer is to use a blanket of granular material beneath either a suspended or ground bearing slab. For ground bearing slabs the granular layer must carry floor loading with minimum deflection.

The grading, shape and density condition requirements for an aggregate in a ventilation layer are largely opposite to those for an aggregate acting as a structural fill. Aggregates suitable for use in a ventilation layer are those which have a high intrinsic permeability, such as large rounded single sized aggregates with minimal sand and fines, in a loose condition. Aggregates suitable for use as a structural fill are those that can be readily compacted to a high density and low permeability, i.e. a well graded gravel and sand about 5% fines.

The structural, material performance and cost implications associated with granular blankets are summarised in Table 19 overleaf.

Table 19: Structure Related Considerations in the Application and Use of an Aggregate Blanket Ventilation Layer

Structural or Material Consideration	Suitability	Advantages or Limitations
1. Type of Structure - Ground level - Split level - Full basement	All types but most suited to structures without partial or full basements	Effective means of linking blankets at different levels required (where split levels or basements occur).
2. Width[(a)] of Structure - Small - Medium - Large	All sizes, but most suited to smaller structure widths.	Effective gas dispersal very limited for medium and large plan area structures. Drain networks incorporated into aggregate blankets can improve gas dispersal characteristics, however careful design of such networks is essential, since the introduction of drains can be counter-productive.
3. Slab Design - Ground bearing - Suspended	Suspended (Ground bearing)[(1)]	[(1)]Where the aggregate ventilation blanket must also act as a bearing layer a compacted, well graded, angular gravel is preferable to readily assure the necessary bearing capacity/settlement characteristics. However, layers formed with such materials will have ineffective gas dispersal characteristics. Single sized, rounded gravels (or cobbles) with minimal compaction are required to meet gas dispersal criteria.
4. Foundation complexity - Simple[(b)] (sympathetic) - Complex (with multiple obstructions and/or changes of level)	Simple Complex	Aggregate blankets are readily formed beneath simple structural arrangements. Some difficulties may be experienced in forming single-sized rounded gravels to profiles, however, such materials may readily be placed around performed pile caps, ground beams and pipe penetrations. Pipe or vent box openings must be provided to interconnect the aggregate blanket through internal ground beams.
5. Membrane location - Below slab - Above slab	Either above or below slab	Membrane installation above the slab is unaffected by an aggregate blanket beneath the slab. For membrane installation below the slab, a regulation/separator layer is required (see 6 below).
6. Membrane installation - Compatibility - Regulation/Separation layer - Handleability - Sequencing	Precautionary measures necessary	A regulation/separator layer is required above the aggregate blanket to provide a consistent surface upon which to lay the membrane. Blinding concrete, boarding or geotextile materials are typically used to form the regulation/separator layer. Aggregate materials are more difficult to control during transportation and placement on site then alternative ventilation media. Therefore sequencing of membrane installation should be carefully programmed to avoid dust and aggregate particles contaminating seams, becoming trapped between the membrane and the regulation layer, etc.
7. Subgrade preparation	No special measures required	
8. Effects of ground settlement	System not particularly sensitive to ground settlements	For ground supported slabs, settlements are readily accommodated by an aggregate blanket. For suspended slabs, ground settlement can create voids at the top of the aggregate layer and thereby locally increase its gas dispersal properties.
9. Other Issues: (i) Thickness of layer (ii) Local availability of materials (iii) Post-construction monitoring (iv) Conversion to active system	Typically thicker than other systems Difficult to monitor Cannot retrofit active system	(i) Thickness depends on material used, placement method etc. Typically 300mm to 500mm. Additional excavation and off-site disposal of contaminated material may be required, compared to other systems. (ii) Gas dispersal blanket material must be uncontaminated, inert, durable and of a consistent specified grading.

Structural or Material Consideration Notes

(a) Width of structure is the dimension between the opposite sides of the building on which ventilation points are sited. Small means less than about 7.5m, Medium means between about 7.5m and 15m, Large means wider than about 15m

(b) Sympathetic means that the underside of the foundation is flat (or slopes up towards the edges of the building) and has a minimum of obstructions (ground beams, pilecaps, partition walls, etc)

10.2 *Results of CFD Modelling*

CFD simulations were carried out on two gradings of gravel (20mm single size aggregate and MOT Type 1 Sub-Base). The results of the modelling for granular blankets are presented numerically in Tables 20, 21 and 22 and shown graphically on Figures 12 and 13. Volume flow rates through the blankets are also shown graphically in comparison with other media on Figures 4 and 5.

The CFD modelling showed:

- MOT Type 1 Sub-Base material is a poor media for the dispersal of gas;
- 20mm single size aggregate only provides an effective media for the dispersal of gas for small width buildings on very low gas potential sites;
- the ventilation performance of a granular blanket is directly proportional to its depth;
- for a 20mm single size aggregate blanket all the pressure drop occurs within the blanket. The pressure drop occurs across the entire width of the blanket;
- the ventilation performance of a granular blanket is insensitive to the side ventilation provision.

Table 20: Results of CFD Modelling of Gravel Blanket of Ventilation Layers: Volume Flow Rate of Air

Foundation Size (m)	Material	Depth of Layer (mm)	Ventilation (mm^2/m)(1)	Volume Flow Rate of Air Through Ventilation Layer (m^3/m width/h)			Volume Flow Rate of Gas into Ventilation Layer (m^3/m width/h)	
				Wind Speed 3m/s	Wind Speed 1m/s	Wind Speed 0.3m/s	Gas Emission Rate 0.05m/s	Gas Emission Rate 0.01m/s
5x5	20mm	200	2652	1.41	0.15	0.002	0.18	0.035
	20mm	400	2652	-	0.31	-	0.18	0.035
	MOT	200	2652	0.25	-	-	0.18	0.035
30 wide	20mm	200	2210	0.19	0.02(2)	-	1.06	0.21
	20mm	200	2210	0.47	0.15(2) 0.04(3)		1.06	0.21
	MOT	400	2210	0.001	-	-	1.06	0.21

(1) on each of 2 sides only
(2) Wind speed 2.0m/s
(3) Wind speed 1.5m/s

Table 21: Results of CFD Modelling for Gravel Blankets Beneath 5m x 5m Foundation: Maximum Hazardous Gas Concentrations

Gas Regime	Material	Depth (mm)	Side Ventilation[1] (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
				Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	20mm	200	2652	0.016	0.123	0.5
	20mm	400	2652	-	0.062	-
	MOT	200	2652	0.079	0.385	-
	MOT	400	2652	0.041	0.248	-
B	20mm	200	2652	0.08	0.62	3.71
	20mm	400	2652	-	0.31	-
	MOT	200	2652	0.4	1.93	-
	MOT	400	2652	0.21	1.24	-
C	20mm	200	2652	0.16	1.24	5
	20mm	400	2652	-	0.62	-
	MOT	200	2652	0.79	3.85	-
	MOT	400	2652	0.41	2.48	-
D	20mm	200	2652	0.32	2.46	14.86
	20mm	400	2652	-	1.24	-
	MOT	200	2652	1.58	7.71	-
	MOT	400	2652	0.83	4.96	-
E	20mm	200	2652	0.63	4.94	20
	20mm	400	2652	-	2.48	-
	MOT	200	2652	3.17	15.42	-
	MOT	400	2652	1.66	9.91	-
F	20mm	200	2652	3.17	20	20
	20mm	400	2652	-	12.4	-
	MOT	200	2652	15.83	20	-
	MOT	400	2652	8.28	20	-

[1] on each of 2 opposite sides only

(shaded) UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 5m x 5m foundation with a 200mm deep 20mm single sized granular blanket are shown in Figures A7.1 to A7.3 in Volume 2.

Table 22: Results of CFD Modelling for Gravel Blankets for 30m Wide Foundation: Maximum Hazardous Gas Concentrations

Gas Regime	Material	Depth (mm)	Side Ventilation(1) (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
				Wind Speed 3.0m/s	Wind Speed 2.0m/s	Wind Speed 1.5m/s
A	20mm	200	2210	0.27	0.45	-
	20mm	400	2210	0.01	0.29	0.42
	MOT	400	2210	0.50	-	-
B	20mm	200	2210	1.36	2.24	-
	20mm	400	2210	0.49	1.47	2.10
	MOT	400	2210	2.5	-	-
C	20mm	200	2210	2.72	4.48	-
	20mm	400	2210	0.98	2.94	4.19
	MOT	400	2210	5.0	-	-
D	20mm	200	2210	5.44	8.97	-
	20mm	400	2210	1.96	5.88	8.38
	MOT	400	2210	9.99	-	-
E	20mm	200	2210	10.88	17.94	-
	20mm	400	2210	3.92	11.76	16.76
	MOT	400	2210	19.98	-	-
F	20mm	200	2210	20	20	-
	20mm	400	2210	19.62	20	20
	MOT	400	2210	20	-	-

1 on each of 2 opposite sides only

(shaded) UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with a 400mm deep 20mm single sized granular blanket are shown in Figures A8.1 to A8.3 in Volume 2.

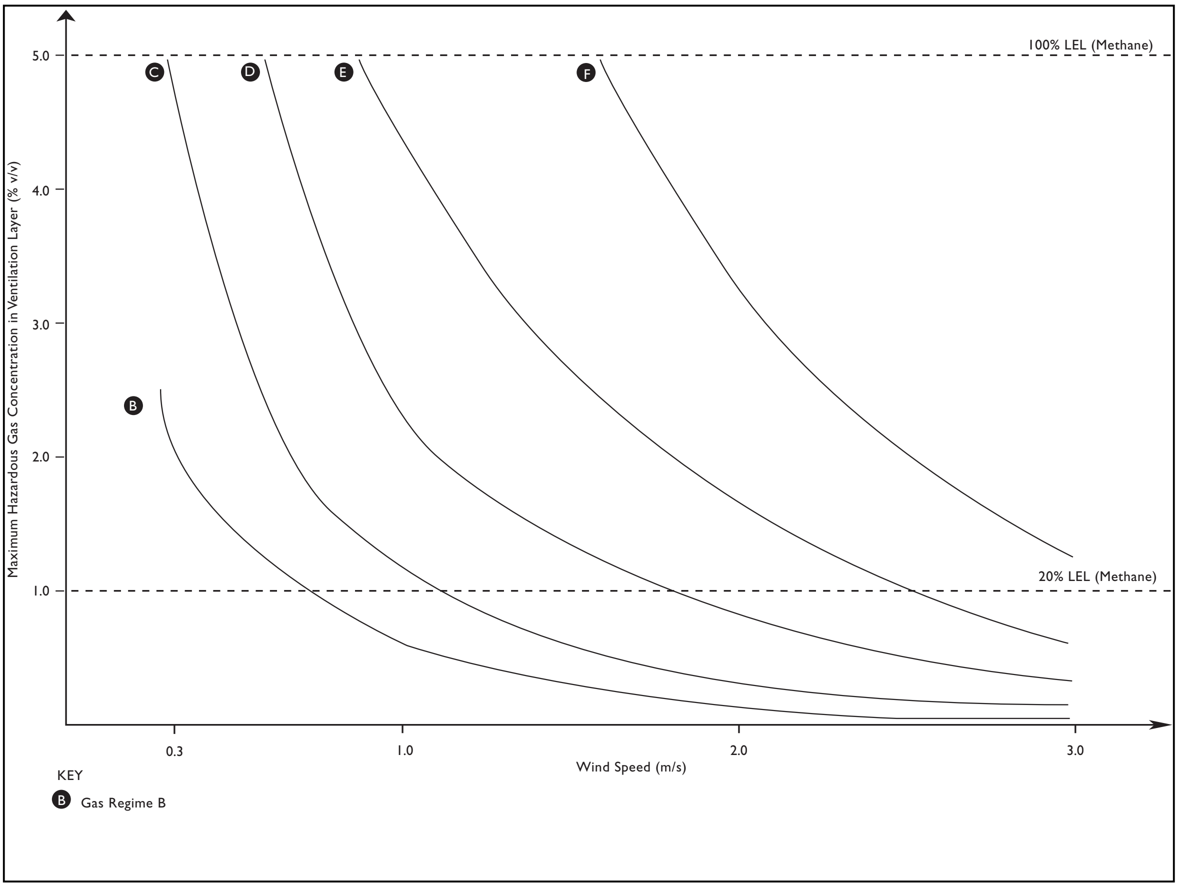


Figure 12
Plot of Wind Speed vs Maximum Concentration: 5m x 5m Foundation, 20mm Gravel Blanket 200mm deep

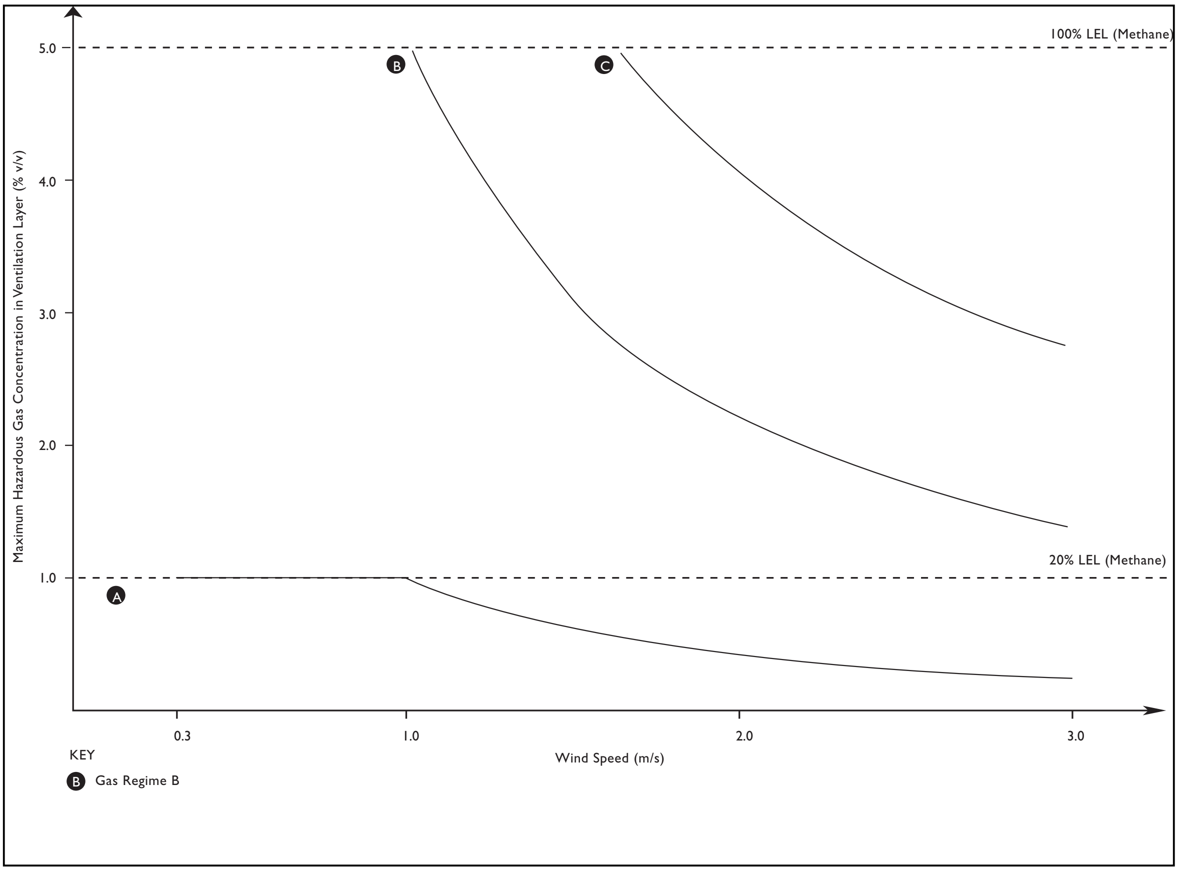


Figure 13
Plot of Wind Speed vs Maximum Concentration: 30m Wide Foundation, 20mm Gravel Blanket, 200mm deep

10.3 Conclusions Regarding the Use of Granular Blanket Ventilation Layers

In view of the CFD simulations carried out for granular blankets, it is considered that:

- MOT Type 1 Sub-Base material is not suitable for use in passive ventilation layers;
- the minimum particle size for material to be used in granular blankets should be 20mm single size;
- the material should be durable under the anticipated exposure conditions and either rounded or sub-angular in shape;
- for a methane hazard granular aggregate blankets are suitable for small width (up to about 7.5m) width buildings for sites up to and including Gas Regime C.
- for large (30m) width buildings the use of granular blankets for a methane hazard should be limited to sites corresponding to Gas Regime A.
- the minimum area of side ventilation is 2000mm^2/m run of wall;
- the minimum layer thickness is 300mm (however, it should be noted that the ventilation performance of a granular blanket is controlled more by the grading and compaction of the blanket than by the thickness of the layer).

11. Granular Blankets With Drain Networks

11.1 General Considerations

11.1.1 Materials and Properties

Pipe materials suitable for sub-floor ventilation purposes include high density polyethylene (HDPE) and polypropylene[(2)]. They should have a minimum diameter of 100mm[(2),(3)]. Other materials currently being used for gas collection pipes include PVC. The pipes must have sufficient strength to withstand the construction process, flexibility to accommodate post construction settlement and creep movements, and durability consistent with the design life of the building and the environmental conditions to which they are exposed.

The efficiency of gas collection pipes is influenced by their open (slotted or perforated) surface area. Waste Management Paper 27[(9)] recommends that the percentage open area of slotted pipes (used for gas collection) is 10%, and many manufacturers will provide perforated pipes with up to 20%. It is recommended that the open area of slotted pipes should be >10% and that a higher open area as possible is used provided such pipes satisfy strength and durability requirements.

As an alternative to slotted or perforated pipes, strips of geocomposite drain may be laid within the centre or at the top of the gravel layer. The strip drains have a lesser depth than pipes and therefore a thinner (and less expensive) granular layer may be required. The strips are usually connected into 100mm diameter collector piping at the edges of foundation.

11.1.2 Layout of Pipes or Geocomposite Strip Drains

The primary influence on the layout and spacing of drains within a granular ventilation layer is the configuration of the building, and in larger buildings the inclusion of interior cross walls, downstanding beams or foundations[(3)]. The drain layout also needs to consider what parts of the network should be gas permeable or plain, where the drain ends should be stopped within the blanket, and the number and size of connections to atmosphere. In order to develop pressure-driven flow though the granular media, pipe networks should not directly connect vents on opposite sides of a building, since this will simply lead to "short circuiting" of the system. Separate arrangements of side vents or interleaved drain networks are needed to supply or vent replacement air into the granular layer.

The structural, material performance and cost implications associated with granular blankets with drain networks are summarised in Table 23 overleaf.

Table 23: Structure Related Considerations in the Application and Use of Aggregate Blanket Ventilation Layer with Network of Gas Drains

Structural or Material Consideration	Suitability	Advantages or Limitations
1. Type of Structure - Ground level - Split level - Full basement	All types but most suited to structures without partial or full basements	Effective means of linking blankets and gas drains at different levels required (where split levels or basements occur)
2. Width of structure[a] - Small - Medium - Large	All sizes	Drain networks can be incorporated into aggregate blankets to improve gas dispersal characteristics (particularly for medium and large plan area buildings). However careful design of such networks is essential, since the introduction of drains can be counter-productive, by "short-circuiting" the flow of fresh air through only part of the blanket.
3. Slab Design - Ground bearing - Suspended	Suspended (Ground bearing[1])	[1] Usually not suitable when ground bearing foundation, since aggregate must be well-graded and well compacted (and therefore has unacceptably low gas permeability to be effective).
4. Foundation complexity - Simple[b] (sympathetic) - Complex (with multiple obstructions and/or changes of level)	Simple Complex much less suitable	Aggregate blankets are readily formed beneath simple structural arrangements, however the layout and spacing of gas drains may be seriously restricted by downstanding elements of complex foundations. Some difficulties may also be experienced in forming single-sized rounded gravels to profiles, however, such materials may readily be placed around performed pile caps, ground beams and pipe penetrations. Gas drains must be carried through internal ground beams.
5. Membrane location - Below slab - Above slab	Either above or below slab.	Membrane installation above the slab is unaffected by an aggregate blanket beneath the slab. For membrane installation below the slab, a regulation/separator layer is required (see 6 below).
6. Membrane installation - Compatibility - Regulation/Separation layer - Handleability - Sequencing	Precautionary Measures necessary.	A regulation/separator layer is required above the aggregate blanket to provide a consistent surface upon which to lay the membrane. Blinding concrete, boarding or geotextile materials are typically used to form the regulation/separator layer. Aggregate materials are more difficult to control during transportation and placement on site then alternative ventilation media. Therefore sequencing of membrane installation should be carefully programmed to avoid dust and aggregate particles contaminating seams, becoming trapped between the membrane and the regulation layer, etc.
7. Subgrade preparation	No special measures required.	
8. Effects of ground settlement	More sensitive than an aggregate blanket without gas drains.	Piped gas drainage networks are not suitable where settlements likely to cause excessive distortions could occur. Blankets beneath suspended floor slabs with piped connections through cross beams are particularly problematic. Geosynthetic gas drains are much more tolerant of ground settlements.
9. Other Issues (i) Thickness of layer (ii) Local availability of materials	Typically thicker than other systems	Thickness depends on material used, placement method, thickness and location of drain etc. Typically 400mm to 600mm where slotted /perforated pipes are used; less if geosynthetic strip drains are used. Additional excavation and off-site disposal of contaminated material may be required, compared to other systems. Gas dispersion blanket material must be uncontaminated, inert, durable and of a consistent specified grading.

Structural or Material Consideration Notes

[a] Width of structure is the dimension between the opposite sides of the building on which ventilation points are sited. Small means less than about 7.5m; Medium means between about 7.5m and 15m; Large means wider than about 15m

[b] Sympathetic means that the underside of the foundation is flat (or slopes up towards the edges of the building) and has a minimum of obstructions (ground beams, pilecaps, partition walls, etc)

11.2 Results of CFD Modelling

CFD modelling was used to investigate the effect of introducing gas collection drains (100mm diameter pipes) into 20mm single size gravel blankets beneath a 5m x 5m and a 30m wide foundation. The arrangements of drains considered are illustrated on Figures 1 and 2.

The CFD modelling assumed that there is no resistance to flow of gas from the gravel into the drain such that any gas that encounters the drain can immediately enter, ie the drain wall has the same or greater permeability than the surrounding gravels. This is considered reasonable for pipe drains with 10% to 20% open area and for geocomposite drains.

The results of the modelling for granular blankets with drain networks are presented numerically in Tables 24, 25 and 26. The results of the modelling of a 30m wide foundation with interleaved pipe drains at 3m centre to centre (Model 5) are also shown graphically on Figure 14. The volume flow rates of air through granular blankets with drains are compared to other media on Figures 4 and 5.

Table 24: Results of CFD Modelling of Granular Blankets with Drain Networks: Volume Flow Rate of Air through 20mm Single Size Gravel Blankets with Fully Permeable Pipe Drains

Foundation Size (m)	CFD Model	Depth of Gravel Blanket (mm)	Ventilation[1] (mm2/m run of wall)	Volume Flow Rate of Air Through Ventilation Layer (m³/m width/h)			Volume Flow Rate of Gas into Ventilation Layer (m³/m width/h)	
				Wind Speed 3m/s	Wind Speed 1m/s	Wind Speed 0.3m/s	Gas Emission Rate 0.05m/s	Gas Emission Rate 0.01m/s
5x5	3	200	2652 3140	1.56	0.20	0.02	0.18	0.035
30 wide	4	400	736 3926	2.13	0.30	0.03	1.06	0.21
	5	400	590 524	2.21	0.59	0.03	1.00	0.21

[1] on each of 2 sides only

The modelling has indicated

5m x 5m Foundation (Models 3 & 6)

- except at very low speeds, a 20mm gravel ventilation layer is more effective without gas collection drains than with the drains;
- the gas collection drains tend to "short circuit" the pathway between the vents on opposite sides of the foundation, especially when connected at both ends to atmosphere;
- reversal of the pressure differential applied to the layer (causing a reversal of flow in the system) produces a different flow, pressure and concentration regime within the layer. However, for the Model 3 arrangement analysed, flow reversal did not produce a significant difference in the maximum concentration in the ventilation layer at an average wind speed (3 m/s) for either 20mm gravel or MOT Type 1 gravel. It was also noted that the areas of highest and lowest concentration remained on the same sides of the foundation;
- more than 95% of the pressure loss in the system occurs in the gravels (i.e. there is very little head loss in the side vents);

Table 25: Results of CFD Modelling for 20mm Single Sized Gravel Blankets with Drains for 5m x 5m Foundation: Maximum Gas Concentrations

Gas Regime	CFD Model	Depth of Gravel Blanket (mm)	Side Ventilation(1) (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
				Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	3	200	2652 3140	0.09	0.28	0.45
	6	200	3140	0.44	-	-
B	3	200	2652 3140	0.47	1.39	2.25
	6	200	3140	2.17	-	-
C	3	200	2652 3140	0.91	2.79	4.51
	6	200	3140	4.35	-	-
D	3	200	2652 3140	1.81	5.58	9.02
	6	200	3140	8.70	-	-
E	3	200	2652 3140	3.64	11.16	18.04
	6	200	3140	17.39	-	-
F	3	200	2652 3140	20	20	20
	6	200	3140	20	-	-

(1) on each of 2 opposite sides only

UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 5m x 5m foundation with a 200mm deep 20mm single sized granular blanket with pipes at 2m c/c connected to atmosphere at one end (Model 3) are shown in Figures A12.1 to A12.3 in Volume 2.
CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 5m x 5m foundation with a 200mm deep 20mm single sized granular blanket with pipes at 2m c/c connected to atmosphere at both ends (Model 6)are shown in Figures A12.1 to A12.3 in Volume 2.

30m wide foundation, gas collection drains @ 2m centres (Model 4)

- comparison of the maximum gas concentrations over 80% of the foundation area with and without collection drains for a 400mm thick 20mm gravel blanket indicates that the ventilation layer is more effective without drains for wind speeds above 2 m/s, but less effective without drains below that wind speed;
- the drains tend to "short circuit" the flow of input air between the opposite sides of the building;
- reversal of the pressure differential caused a maximum of about 20% difference in the maximum gas concentration in the layer. However, for gas flow in both directions, the area of lowest gas concentration was the region closest to the vents not connected to pipework, and the area of highest gas concentrations at the opposite end (and edges to the foundation);

Table 26: Results of CFD Modelling for 20mm Single Sized Gravel Blankets with Fully Permeable Pipe Drains for 30m Wide Foundation: Maximum Gas Concentrations over 80% of Ventilation Layer

Gas Regime	CFD Model	Depth of Gravel Blanket (mm)	Side Ventilation(1) (mm²/m run wall)	Maximum Hazardous Gas Concentration (%v/v)		
				Wind Speed 3.0m/s	Wind Speed 1.0m/s	Wind Speed 0.3m/s
A	4	400	736 3926	0.19	0.29	0.47
	5	400	590 524	0.08	0.18	0.44
B	4	400	736 3926	0.95	1.47	2.35
	5	400	590 524	0.42	0.92	2.22
C	4	400	736 3926	0.90	2.93	4.71
	5	400	590 524	0.84	1.84	4.44
D	4	400	736 3926	3.81	5.87	9.44
	5	400	590 524	1.69	3.66	8.88
E	4	400	736 3926	7.62	11.74	18.87
	5	400	590 524	3.38	7.33	17.76
F	4	400	736 3926	20	20	20
	5	400	590 524	20	20	20

(1) on each of 2 opposite sides only

[shaded] UNSUITABLE with respect to example gas dispersal performance criteria (Section 6.5, Figure 3.1)

CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with a 400mm deep 20mm single sized granular blanket with pipes at 2m c/c with one end connected to atmosphere (Model 4) are shown in Figures A10.1.1 to A10.2.3 in Volume 2.
CFD output plots showing steady state speed, pressure and concentration at 3m/s wind speed for a 30m wide foundation with a 400mm deep 20mm single sized granular blanket with interleaved pipes at 3m c/c (Model 5) are shown in Figures A11.1 to A11.3 in Volume 2.

- approximately 85 percent of the pressure loss occurs within the 20mm gravel at an average (3 m/s) wind speed, whereas more than 95% of the pressure loss occurs in the gravels at a low (0.3 m/s) wind speed;
- the gas collection drains are effective in minimising differential pressures within the gravel ventilation layer;

30m wide foundation, gas collection drains interleaved at 3m centres (Model 5)

- comparison of the maximum gas concentrations over 80% of the foundation area with and without collection drains for a 400mm thick, 20mm gravel blanket indicates that the ventilation layer is significantly more effective with the gas collection drain network for the more critical below-average wind speeds.
- at an average wind speed (3.0m/s) the maximum gas concentration is less without the pipe network, however, the gas concentration plot shows that 80% of the area of the ventilation layer with pipes is at a lesser concentration than the maximum predicted without pipes;
- the drain arrangement produces good distribution of dilutant air throughout the blanket, except along the unventilated edges of the layer;
- only approximately 20% of the applied pressure head is lost in the ventilation layer at a wind speed of 3 m/s, the remaining pressure loss occurring across the side vents and in the side vent pipework. This is indicative of a relatively high throughput of dilutant air, associated with a short (3m) path length through the gravels between the inlet and discharge drain networks.

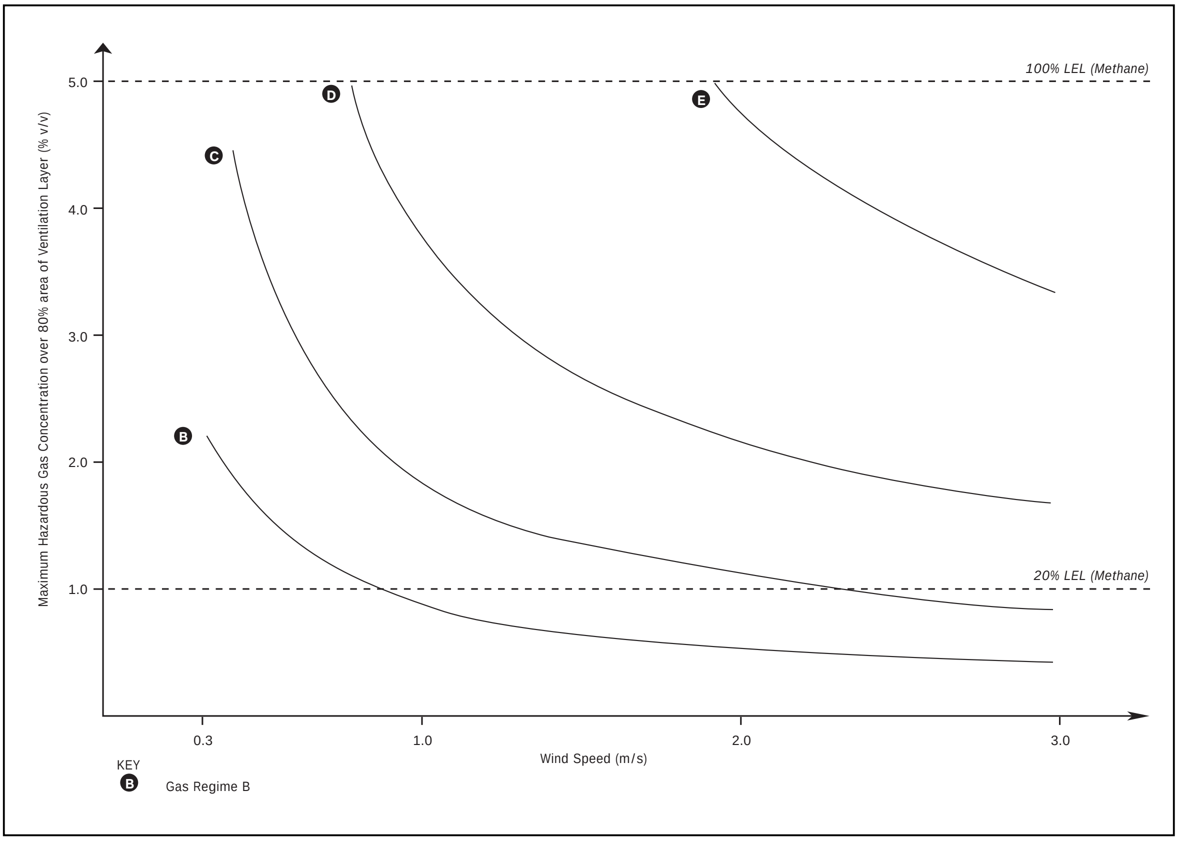


Figure 14 Plot of Wind Speed vs Maximum Concentration Over 80% Area Ventilation Layer: 30m Wide foundation, 20mm Gravel Blanket 400mm deep with Pipe Drains at 3m Centres

11.3 Conclusions Regarding the Use of Granular Blankets with Drains

The CFD simulations carried out for granular blankets with drain networks have provided a valuable insight into the pressure distribution and flow patterns through idealised systems. The modelling has shown that drains do not have a significant beneficial effect on small width building, and can in fact impair performance. The installation of a carefully designed drain network can significantly improve the gas dispersal characteristics of a granular blanket beneath a wide foundation. Conclusions and recommendations than can be inferred from the CFD simulations are as follows:

- for large (30m) width buildings granular blankets with drain networks are suitable for sites up to and including Gas Regime B ;
- one end of the drain network should be stopped within the granular layer, (the drain network should not directly connect the opposite sides of the building);
- effective drain arrangements are those where the opposite sides of the building are each connected to separate drainage networks, interleaved with each other (for example as simulated in Model 5);
- as far as practical drainage networks should be symmetrical;
- to achieve a balanced system (and avoid short-circuiting) the distance between the inlet and discharge network drains should be approximately equal throughout the system and between about 2m and 3m in width for a layer composed of 20mm gravel;
- drains should be placed parallel and not more than 1m distant from unventilated edges of the blanket to be effective;
- gas collection drains (pipes) with a smooth internal surface so as not to effect the flow of air through them are preferred, particularly for the header pipe system.
- the grading, thickness and degree of compaction of the granular media has a significant impact on the gas dispersal effectiveness of granular blankets with drains. A minimum layer thickness of 300mm is proposed.

12. Membranes

Low permeability gas barriers act as an additional secondary protection in a passive gas protection system and consist of the concrete ground slab, underlain (or overlain) by an overlapped, taped or welded synthetic membrane. The principal function of the low permeability gas barrier is to prevent gas from entering the building through shrinkage cracks, construction joints, service openings etc in the floor slab during periods when the natural forces causing dilution and dispersion within the ventilation layer are insufficient. Therefore, the membrane should cover the whole plan area of the structure to all external faces to seal both the ground slab and also any cavity walls and voids in hollow concrete block work.

Membranes can be installed either above the concrete floor slab (below a secondary slab or screed), or below the floor slab on a permanent substrate. The placement of the membrane is dependent both on the type of ventilation layer used and on the proposed use of the building. In situations where it is possible that there could be damage to the floor due to retrofitting services or fixings, or very high point loads that could cause spalling, membranes should be placed beneath the floor slab.

12.1 Materials and Properties

The principal consideration with the selection of gas proof membranes is not with placement but with installation and continuity after placement. Membrane material most commonly used in passive gas protection systems is polyethylene. The polyethylene sheets can be reinforced with grids or screens of high density polyethylene, polypropylene or polyester to give a material with improved tensile strength and tear resistance. Aluminium foil can also be included to provide much reduced permeability to methane and other gases.

The ability of a membrane to withstand damage during placement and installation is largely determined by its tensile properties, particularly:

(i) tensile strength;
(ii) puncture/abrasion resistance;
(iii) tear resistance;
(iv) resistance to ultraviolet light (that can cause embrittlement) if likely to be left exposed for longer than the normal installation period); and
(v) workmanship.

12.2 Installation

Manufacturers of membranes provide instructions on how to properly lay and install gas proof membranes and should be consulted prior to installation of any membrane. The principal consideration when installing a membrane are given below.

(i) Adequate quality control is very important when laying a membrane to ensure that no damage occurs.
(ii) Membranes should be protected from overlying trades either by the use of temporary boards or sheeting over the whole area, or by immediate laying of the upper slab or floor screed. Protection of the underside of membrane may also be required in certain situations, eg when using a granular blanket or double impacted geocomposits as the ventilation layer. A no fines concrete blinding layer of minimum thickness of 50mm or a suitable geotextile should be used.
(iii) All membranes should be continuous over the whole plan area of the structure. Cavity walls, voids formed in hollow concrete block walls etc, should be sealed to avoid gas accumulating in them. Careful consideration of the detailing of the gas impermeable dpc should be undertaken to avoid creation of slip planes in construction.

(iv) Continuity of membranes can be achieved by joining separate membrane panels by either overlapping (for self adhesive membranes), taping or welding.

(v) For membranes to be overlapped or taped, the separate panels should be overlapped in accordance with manufacturer's instructions. The joint should have at least the equivalent gas transmission properties as the surrounding membrane.

(vi) When using thermal fusion/melt bonding on polyethylene membranes the degree of heat applied needs to be carefully controlled. Too little heat results in poor seam strength and too much weakens the membrane. Particular care also needs be applied in using thermal fusion/melt bonding on thin membranes containing aluminium in order not to completely melt through the polythene layers and damage the aluminium sheet.

(vii) Elongation of the membrane should be avoided. Aluminium in particular has a very low coefficient of elasticity and will rupture if the membrane elongates, even slightly. The use of HDPE grids and multi-layer LDPE sheets will reduce the ability of the membrane to elongate. If unreinforced membranes containing aluminium are used, then they should be bonded to the slab to prevent elongation.

(viii) Edges and corners around floor slabs, ground beams, columns and service pipes should ideally be sealed with preformed membrane sections which are either welded to the underlying membrane or fixed with adhesive. Additional protection can be achieved by using a bitumen based or equivalent sealing tape, to secure the preformed section. Advice on the minimum overlap required to ensure a reasonable gas tight seal should be sought by consultation with membrane manufacturer.

(ix) If the gas membrane is separate to the damp proof course (dpc) the two membranes should be joined in such a way so as not to affect the frictional resistance of the dpc.

(x) Service penetration should enter the building above the sealed floor slab, where this is not possible the penetrations should be kept to a minimum. Where services need to penetrate the ground slab and membrane they should be sealed into a slab using a suitable sealant and the membrane should be completely sealed around the protruding service.

(xi) Prior to laying the upper slab or floor screed the membrane should be inspected to ensure that no damage has occurred during installation. Any damage should be repaired to ensure a gas tight seal. Inspection and repair of the membrane should be carried out by either the membrane manufacturer or a qualified installation contractor. This inspection may also constitute a statutory notification to building control.

13. *Summary of Gas Dispersal Characteristics of Ventilation Media*

The CFD simulations have shown that:

- All the ventilation media studied are suitable for foundations up to 30m width for situations discussed in BRE 212[2], ie where the methane concentration is at or below 1% by volume (Gas Regime A).
- Open void spaces provide good ventilation for small width foundation at all gas regimes studied and for large width foundations on sites up to and including Gas Regime E.
- Polystyrene shuttering with an equivalent clear void depth of 22mm provides good ventilation for small width foundation on sites up to and including Gas Regime E and for large width foundations on sites up to and including Gas Regime C.
- Polystyrene shuttering with an equivalent clear void depth of 100mm provides good ventilation for small width foundation on sites with gassing regimes up to and including Gas Regime E and for large width foundations on sites up to and including Gas Regime E.
- A 40mm double sided geocomposite blanket provides good ventilation for small width foundation on sites up to and including Gas Regime E and for large width foundations on sites up to and including Gas Regime B.
- A 20mm single size gravel blanket provides good ventilation for small width foundation on sites up to and including Gas Regime B. For large width foundations granular blankets should be limited to sites corresponding to Gas Regime A
- Granular blankets with drains are suitable for large width foundations on sites up to and including Gas Regime B.

A summary of the gas dispersal characteristics of the various ventilation media studied for the different gas regimes is shown in Table 27 overleaf.

				Open Void Space[6]		**Polystyrene Shuttering[6]**				**Geocomposite Drainage Blanket**		**20mm Single Size Gravel Blanket**		**20mm Single Size Gravel Blanket with Interleaved Pipes at 3m Centres[3]**
						Equivalent Clear Void Depth 22mm		**Equivalent Clear Void Depth 100mm**		**Equivalent Clear Void Depth 36mm**				
Foundation Width[4]				5m	30m	5m	30m	5m	30m	5m	30m	5m	30m	30m
Gas Regime				**Gas Dispersal Characteristics of Media for Methane Hazards**										
Gas Regime	Methane Conc. (%v/v)	Emission Rate[1] (m/s)	Char Situ[2]											
A[5]	1	0.005	2	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
B	5	0.005	3	Very Good	Very Good	Very Good	Good	Very Good	Very Good	Very Good	Good	Good	Poor	Good
C	5	0.01	4	Very Good	Very Good	Very Good	Good	Very Good	Very Good	Very Good	Fair	Fair	Unsuit	Fair
D	20	0.005	4	Very Good	Very Good	Very Good	Fair	Very Good	Good	Good	Poor	Poor	Unsuit	Poor
E	20	0.01	4	Very Good	Good	Good	Poor	Very Good	Good	Good	Unsuit	Poor	Unsuit	Unsuit
F	20	0.05	5	Good	Poor	Fair	Unsuit	Fair	Poor	Fair	Unsuit	Unsuit	Unsuit	Unsuit

1 Emission rate values refer to equivalent total gas flow velocity from 50mm diameter borehole and Peckson(12) assumption
2 Characteristic situation after CIRIA Report 149(3)
3 Gas Dispersal Characteristics based on maximum steady state concentration over 80% area of foundation, pipes at interleaved 3m centres
4 Assumes sympathetically detailed underside of foundation
5 Gas dispersal characteristics have not been assessed using Figure 3, since maximum concentration entering the ventilation layer is equivalent to the target concentration
6 For open void space and polystyrene shuttered ventilation layers additional side ventilation provision can improve the gas dispersal characteristics

Table 27 Summary of Gas Dispersal Characteristics of Different Ventilation Media on Idealised Foundations

14. References

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