BS 8485:2015

BSI Standards Publication

Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings

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Published by BSI Standards Limited 2015

ISBN 978 0 580 83071 6

ICS 91.120.99; 91.200

The following BSI references relate to the work on this document:
Committee reference EH/4
Draft for comment 15/30283599 DC

Publication history

First published October 2007
Second (present) edition, June 2015

Amendments issued since publication

Date	Text affected

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This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 86, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 June 2015. It was prepared by Technical Committee EH/4, *Soil quality*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 8485:2007, which is withdrawn.

Information about this document

This is a full revision of the standard, and introduces the following principal changes:

- inclusion of more detailed recommendations on the interpretation of gas monitoring data and assignment of the gas screening value;
- inclusion of four building type definitions and amendments to the gas protection scores recommended for different characteristic situations;
- inclusion of recommendations for reporting of gas protection measures at the design, installation and post-construction (verification) stages;
- revision of recommendations on the design of ventilation protective measures;
- inclusion of recommendations on membrane selection and verification;
- inclusion of a method of site characterization without gas monitoring data (based on RB17 [1]);
- inclusion of worked examples of solution choices for a range of different ground gas conditions and building types;
- inclusion of informative guidance on radon gas and volatile organic compounds in Annex G and Annex H, respectively;
- inclusion of cross references to BS 8576:2013 and BS 10175:2011+A1:2013 as the key sources of good practice on investigations for ground gas; and
- inclusion of cross references to other relevant UK good practice guidance published since the publication of BS 8485:2007, including guidance from CIRIA, NHBC, CL:AIRE and Wilson, Card and Haines.

Use of this document

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word "should" is used to express recommendations of this standard. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the Clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Introduction

Toxic, asphyxiating and flammable and potentially explosive ground gases can enter buildings and other structures on and below the ground. They variously pose potential risks to occupants and users, and to the structures themselves.

This British Standard is intended to be used by designers of gas protection measures and by regulators involved in the assessment of design solutions. It recognizes that there are a number of factors requiring consideration which affect the sensitivity of a development to the effects of ground gas, and that there is a range of design solutions available for different situations. It is anticipated that specialist advice is needed in the assessment of the ground gas data and in the risk assessment phase.

This British Standard provides a framework, in line with *Model procedures for the management of land contamination,* CLR11 [2], which provides designers with information about what is needed for an adequate ground gas site investigation. It also provides an approach to determine appropriate ground gas parameters that can be used to identify a range of possible design solutions for protection against the presence of methane and carbon dioxide on a development site. The framework is not prescriptive and professional judgement may be made as to the acceptability of risk and whether there might be benefit in undertaking more rigorous site assessment or adopting conservative measures in design. Emphasis is placed on the justification and recording of risk assessments and design decisions throughout the process.

A variety of gases might be present in the ground naturally, or be present as a result of contamination of the ground, or arise from buried wastes. In addition to the main components found in air (nitrogen and oxygen), ground gas can contain other gases (e.g. methane, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, helium, neon, argon, xenon, radon, etc.). It can also contain volatile organic compounds (VOCs) or inorganic vapours (mercury).

Methane (which is flammable and an asphyxiant) and carbon dioxide (which is toxic and an asphyxiant) can originate from a range of sources including:

- land-filled wastes;
- degradable material present within the soil matrix of made ground;
- peat and organic matter within alluvial deposits;
- migrating landfill leachate;
- spilled or leaked petroleum hydrocarbons;
- silt formed in water bodies (e.g. ponds, docks and rivers);
- some natural deposits (e.g. chalk and coal measure strata); and
- leaks of mains gas (natural gas) and sewer gas.

Wherever biodegradable materials are present, microbial activity produces methane and/or carbon dioxide depending on whether conditions are aerobic or anaerobic. A number of additional trace gases can also be produced.

Permanent gases such as methane, carbon dioxide and carbon monoxide which might be present in coal measure strata can also emanate from old mine workings (guidance is given in *CIRIA Report 130* [3]). Combusting coal measure strata, including waste in colliery spoil tips, can release carbon monoxide, as can smouldering domestic waste. Under some circumstances, sulfur rich deposits such as gypsum waste and some slags can release substantial quantities of hydrogen sulfide; for example, when sulfur-bearing wastes and domestic refuse are mixed.

1 Scope

This British Standard gives recommendations on ground gas site characterization and the choice of solutions for the design of integral gas protective measures for new buildings to prevent entry of carbon dioxide and methane, and provide a safe internal environment.

This British Standard gives a process that can be used to demonstrate that risks posed by the potential or actual presence of carbon dioxide and methane have been addressed.

This British Standard does not cover protection of new buildings against other hazardous ground gases. Nor does this British Standard cover protection of buildings into which methane and carbon dioxide might be introduced by the activities for which they are used (for example, water pumping stations).

The retrospective design of protection measures for completed buildings and the design of retrospective protection measures after completion of building construction are not covered in this British Standard.

NOTE 1 Guidance on radon and VOCs is given in Annex G and Annex H.

NOTE 2 This British Standard does not give recommendations on oxygen depletion.

NOTE 3 The assessment and decision making stages are presented in the form of process flow charts (Figure 3, Figure 5 and Figure 6), accompanying information and explanatory guidance and, where appropriate, references to other guidance and information. The contents of this British Standard are shown in the document flow chart in Figure 1.

NOTE 4 Full protection of buildings might require a range of measures (for example, to control gas migration, to protect car parking and garden areas, and to monitor gas concentrations) in addition to those incorporated into the building. However, guidance on these is not provided and is available in the Ground Gas Handbook [4] and CIRIA Report 149 [5].

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 8576:2013, *Guidance on investigations for ground gas – Permanent gases and Volatile Organic Compounds (VOCs)*

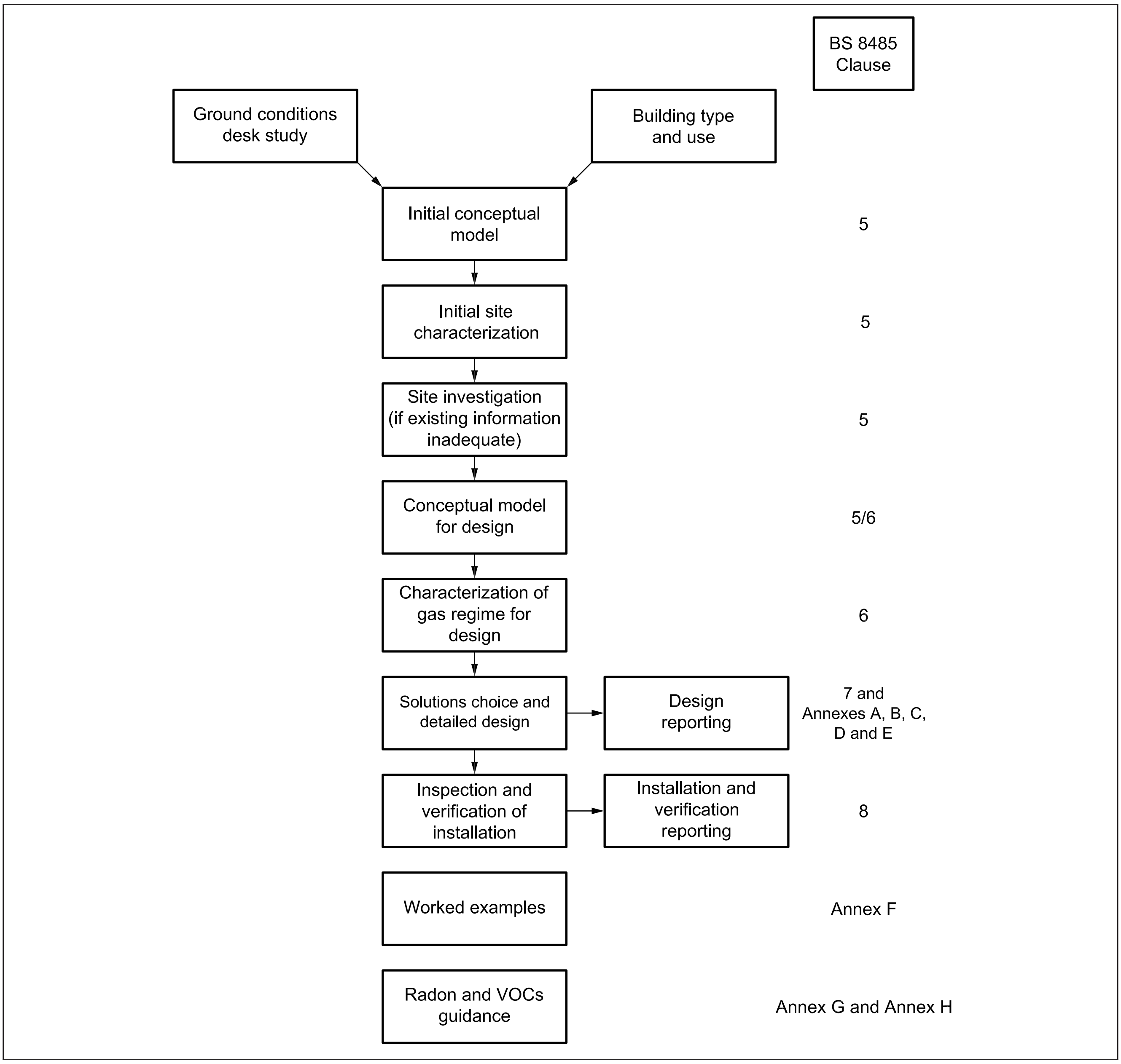
BS 10175: 2011+A1:2013, *Investigation of potentially contaminated sites – Code of practice*

BS EN 13137, *Characterisation of waste – Determination of total organic carbon (TOC) in waste, sludges and sediments*

Other publications

[N1] MALLETT, H., COX, L. (nee TAFFEL-ANDUREAU), WILSON, S. and CORBAN, M. *Good practice on the testing and verification of protection systems for buildings against hazardous ground gases (C735).* London: CIRIA, 2014.

Figure 1 **BS 8485 document flow chart**



3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS 8576, BS 10175 and BS EN ISO 11074 and the following apply.

NOTE Where definitions differ between BS 8576 or BS 10175 and BS EN ISO 11074, those from BS 8576 and BS 10175 are to be used.

3.1 borehole hazardous gas flow rate (Q_{hg})

flow rate (volume per unit time) of a specific hazardous gas (Q_{hg}), either methane or carbon dioxide, from a borehole standpipe

NOTE 1 It is calculated from individual borehole measurements of total gas flow emission and the concentration of the specific hazardous gas.

NOTE 2 Q_{hg} *is usually expressed as litres per hour (L/h).*

NOTE 3 The majority of borehole standpipes installed in contamination ground investigations are of 50 mm internal diameter although other diameter pipes are also sometimes used.

3.2 characteristic gas situation (CS)
ground gas regime assumed for design of gas protective measures from the refined conceptual site model after an adequate site investigation

NOTE Characteristic gas situations range between CS1 (very low hazard potential) to CS6 (very high hazard potential) and have a defined range of gas screening values.

3.3 gas resistant membrane
membrane placed above, below or within the floor slab construction (and walls of a basement) to restrict methane and carbon dioxide migration from the ground into a building

3.4 gas screening value (GSV)
flow rate of a specific hazardous gas representative of a site or zone, derived from assessment of borehole concentration and flow rate measurements and taking account of all other influencing factors, in accordance with a conceptual site model

NOTE 1 This definition is different from the definition of GSV in CIRIA C665 [6].

NOTE 2 GSV is based on measured data but ultimately derived using professional judgement.

3.5 ground gas
all gases occurring and generated within the ground whether in made ground or natural deposits

NOTE The reference to all gases includes methane, carbon dioxide and VOCs or inorganic vapours.

3.6 made ground
all deposits which have accumulated through human activity and may consist of natural materials and/or materials manufactured by man in some way, such as through crushing or washing, or arising from an industrial process

3.7 measured flow rate (q)
total gas flow from a borehole standpipe measured in volume per unit time

3.8 measured hazardous gas concentration (C_{hg})
quantity of a hazardous gas measured as a percentage of the total volume of gas flowing from a borehole standpipe

3.9 monitoring event
occasion on which ground gas data, other relevant information or samples are collected

[SOURCE: BS 8576:2013, **3.5**]

*NOTE Periodic monitoring, high-frequency monitoring and continuous monitoring typically comprise a number of monitoring events varying from a few to many. See BS 8576:2013, **3.1**, **3.4** and **3.9** for further information.*

3.10 permanent gas
element or compound that is a gas at all ambient temperatures likely to be encountered on the surface of the earth

[SOURCE: BS EN ISO 11074, **4.1.16**]

NOTE Under extremely hot circumstances, some substances might become gases that would not otherwise be. These are not permanent gases.

4 Overview of ground gas protection

COMMENTARY ON CLAUSE ***4***

Toxic, asphyxiating and flammable and potentially explosive ground gases can potentially enter buildings and other built structures, and consequently pose various risks to occupants and users, and to the structures themselves. Potential gas ingress routes and areas of gas accumulation for a conventional residential property are illustrated in Figure 2.

Gas protection measures are most commonly required when there are sources of ground gases beneath the building or at a nearby location or depth at which it is not feasible to prevent gas migrating to beneath the building.

It might also be necessary to apply gas protection measures to the building when an external barrier is in place for an off-site gas source, as an additional protection measure for the building, in case the barrier fails to work as intended.

To complete an assessment of the risks posed by the presence of permanent and other ground gases, the potential sources of gas in and around a site should be identified; guidance on the collection of the relevant information is provided in BS 8576.

NOTE 1 It is usually also necessary to collect information on other aspects of the site and the surrounding land, including, for example, the natural and man-made geology of the site and surrounding areas, the hydrogeological regime, and the current and historical uses of the site and surrounding land. These aspects are dealt with in BS 10175.

Protection should be provided by:

a) preventing gas entering buildings;

b) designing to avoid the build-up of hazardous gas beneath buildings or in subsurface infrastructure, e.g. inspection chambers and service runs; and

c) designing to avoid the build-up of hazardous gas within buildings.

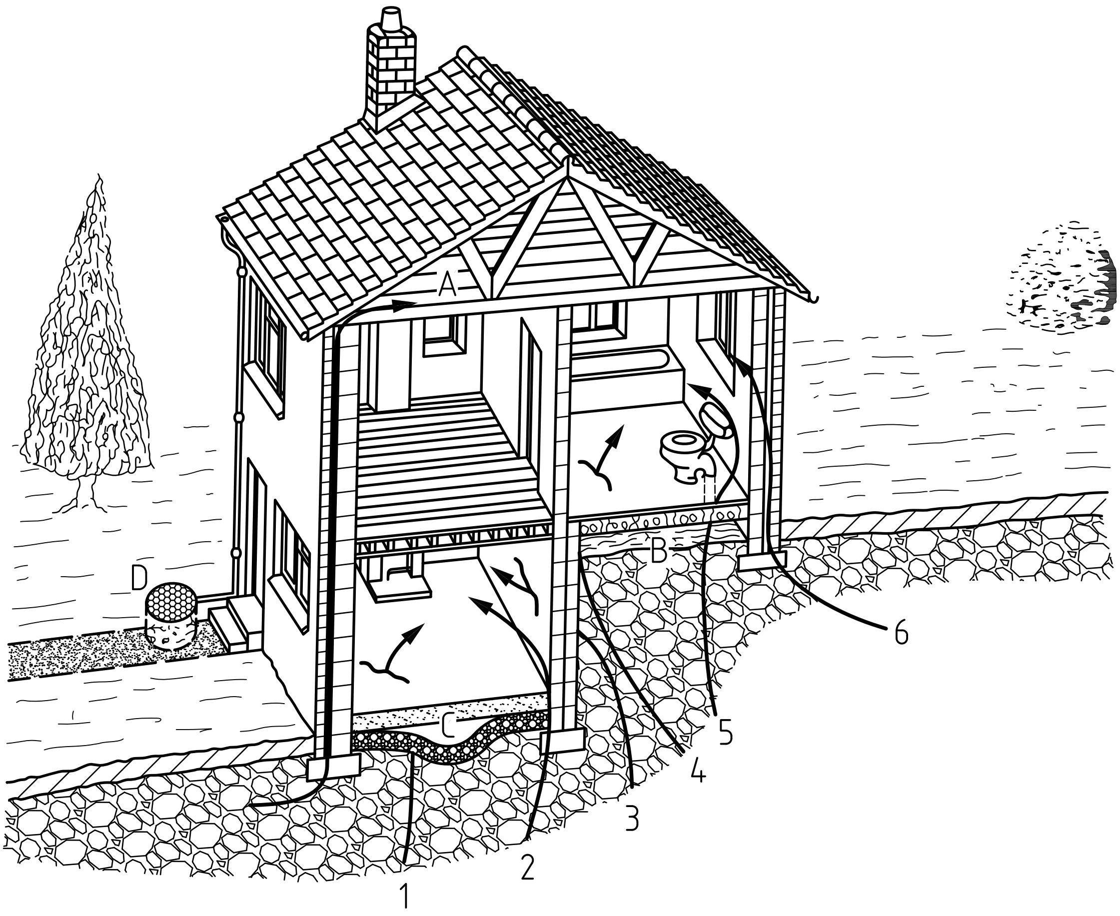
NOTE 2 Protective measures are given in Clause 7 and Annex A, Annex B and Annex C.

NOTE 3 The following additional protection measures might be required:

- *monitoring during occupation or use;*
- *management measures (see* ***7.1****);*
- *site-wide measures designed to reduce the gas hazard beneath the building.*

Guidance on these additional measures is not provided in this British Standard but can be found in a number of published guidance documents including Ground Gas Handbook [4] and CIRIA Report 149 [5].

Figure 2 **Key ground gas ingress routes and accumulation areas within unprotected conventional residential buildings**



Key

1	Through cracks and openings in solid concrete ground slabs if present due to shrinkage and curing
2	Through construction joints and openings at wall-foundation interface with ground slab if not sealed
3	Through cracks in walls below ground level
4	Through numerous gaps and openings in suspended block and beam floors or timber floors
5	Through gaps around service pipes and ducts or within the ducts
6	Through cavity walls
A	Roof voids
B	Beneath suspended floors
C	Within settlement voids below floor slab
D	Drains and soakaways (or similar voids)

NOTE This Figure is Figure 3 from CIRIA Report 149 [5] reproduced with the kind permission of CIRIA.

The measures used should be:

a) effective: in that they do what they are intended to do;

b) robust: in that they are not easily compromised, particularly during construction;

c) durable: in that they remain effective for the required design life; and

d) buildable: in that they can be built given an appropriate standard of workmanship, supervision and verification.

Effectiveness should be assessed in terms of:

- the theoretical effectiveness assuming perfect installation; and
- the practical effectiveness (i.e. what it is reasonable to expect to achieve under normal conditions); and
- likely long-term effectiveness given the likely durability of materials, etc.

Extreme events (e.g. exceptional changes in atmospheric pressure, rapid groundwater rise and/or flooding) should be taken into account when defining the CS (see **6.2.1**) and when selecting the protective measures.

Protective measures should include the use of materials that have a defined design life or no known critical time deterioration properties, and should be placed where they might reasonably be expected to continue to perform for the life of a building, that might be in excess of 100 years.

*NOTE 4 Measures (especially ventilation) can be designed from first principles (see **6.2**) or selected from "deemed to satisfy" solutions following the recommendations in Clause **7**.*

Risk assessment and all design decisions should be documented and recorded in the design phase report (see **8.1**).

5 Site investigation for ground gases

5.1 General

Investigations for ground gas should be carried out in accordance with BS 8576, which gives guidance on carrying out a preliminary investigation prior to any field work (see **5.2** for how to carry out a preliminary investigation). Before embarking on the design of protective measures, designers should check that the site investigation has been carried out in accordance with BS 8576 and BS 10175 and that it has provided data that is sufficient for the task in hand in terms of type, quantity and quality of the data and other information obtained.

*NOTE 1 The process of ground gas site investigation (given in **5.2** to **5.4**) and interpretation of the investigation results (given in **6.1** to **6.3**) are summarized in Figure 3.*

The evaluation of the adequacy of the site investigation should be carried out in accordance with Table 1.

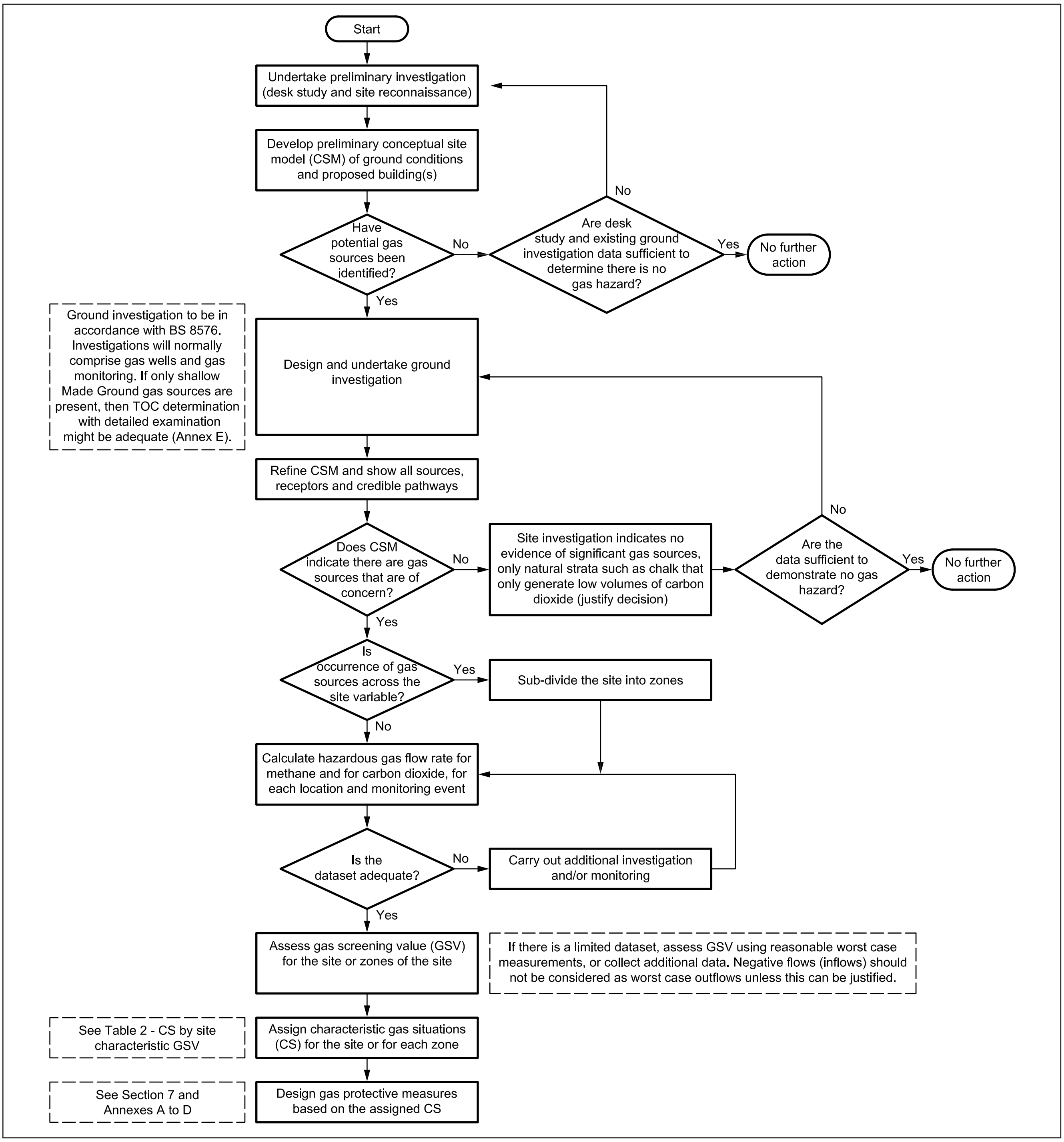
NOTE 2 Guidance on the sufficiency of gas monitoring data is provided in BS 8576:2013, Annex F.

5.2 Preliminary investigation

The first phase of site investigation that should be undertaken is the preliminary investigation (desk study and site reconnaissance).

Information about the history and current use(s) of the site and its surrounding area should be used to identify the likely ground gas sources, migration pathways and receptors.

Figure 3 **Ground gas site characterization and assessment flow chart**



All potential gas sources should be identified; these sources might include natural geological sources, mine workings, waste materials, landfills and made ground. For each source an understanding of the nature of the gas generation processes involved should be formulated.

NOTE 1 Some of the sources might be discounted as not being of concern during further investigation and subsequent assessment.

Table 1 **Check list for assessing the adequacy of a site investigation**

Aspect of the investigation	Questions that should be adequately answered
Preliminary investigation	Has the preliminary investigation (desk study and site reconnaissance) been completed in accordance with BS 10175 and BS 8576? Are there any information gaps that need to be filled?
Scope of the investigation	Has the investigation been sufficient in scope to: • establish the geology and hydrogeology of the site; • determine whether made ground and/or contamination is present; and • identify source(s) and the nature of the mechanism of gas generation? Has appropriate monitoring, sampling and analysis been carried out?
Geophysical techniques	Where appropriate, have geophysical/remote sensing techniques been used to help delineate the extent of landfill or made ground and the location of the methanogenic material?
Monitoring installations	Were the type and depth of monitoring installations and response zones adequate to identify on-site gas sources and migration pathways, and to determine whether receptors were likely to be impacted? Are there sufficient monitoring installations to evaluate effects of off-site sources, where this is relevant?
Distribution of monitoring points	Were monitoring locations distributed such that sources, migration pathways and receptors can be adequately characterized?
Monitoring instrumentation	Were the instruments used to monitor gas appropriate, and properly maintained, calibrated and operated?
Monitoring parameters	Is enough information regarding gas composition, concentrations, atmospheric and differential borehole pressures and flows available to characterize risk, and is there sufficient data concerning the factors that affect gas migration and emission to assess the likely variability of the gas regime? Was the data accurately measured and reported?
Monitoring frequency	Was the frequency of monitoring sufficient to characterize the consistency or inconsistency of the gas regime over the monitoring period (see **5.3**)?
Monitoring period	Was the period of monitoring long enough to monitor changes in ambient conditions that influence gas generation and migration (see **5.4**)?

The geology and hydrogeology of the site, and the presence of contamination, and how it might affect gas sources and gas migration should be assessed; this includes assessing the effect of groundwater level variations, including tidal variations (and how these can affect gas sources and gas migration).

All potential pathways should be identified, which includes natural geological pathways, services, underground structures and mine workings. Pathways that are not credible should be discounted.

Potential receptors, both on- and off-site, should be identified and their sensitivity assessed.

The desk study should be used to develop the preliminary conceptual site model that guides the approach to assessing gas risk on a site and the requirements for field investigation, laboratory testing and gas monitoring.

NOTE 2 Guidance on the development of the preliminary conceptual site model is given in BS 8576:2013, Clause ***6****.*

5.3 Field investigation and monitoring

The need for an intrusive investigation to be designed to assess ground gases at different lateral and depth zones, and/or for samples to be collected for total organic carbon (TOC) should be determined, taking the desk study into account.

NOTE 1 For example, where a site encompasses an old landfill area and adjoining area of natural ground, then boreholes located in the landfill are likely to define the source hazard that directly impacts any development above.

Boreholes in the natural ground (external to the old wastes) should be located and designed to assess the migration pathway.

NOTE 2 There might be a reduction in gas hazard with increasing distance from the source, if the site is sufficiently large.

The design and implementation of field investigations for ground gases should be in accordance with BS 8576:2013, Clause **7** to Clause **12**.

The TOC of soils should be determined using the method in BS EN 13137.

NOTE 3 Different methods of determination of TOC give different results.

5.4 Conceptual site model for design of gas protection system

The information gathered during the site investigation should be used to refine the preliminary conceptual site model and provide the conceptual site model for design purposes (see Figure 3 and BS 8576:2013, Clause **13**).

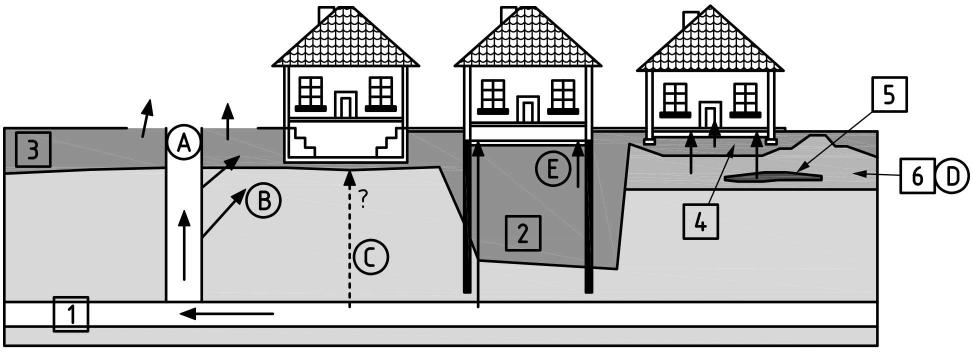
The conceptual site model should define the ground gas sources, the sensitive receptors (persons using the building, and the building structure and fabric) and the pathways between the sources and receptors.

NOTE 1 Receptors are most at risk in spaces within the building where gas could accumulate to concentrations that are potentially explosive or harmful to human health.

NOTE 2 Example cross-section conceptual site models for design are given for gas sources below buildings and off-site from the building in question in Figure 4.

The conceptual site model should also include plans or other information that are required to demonstrate an understanding of the ground and gas sources in and around the site.

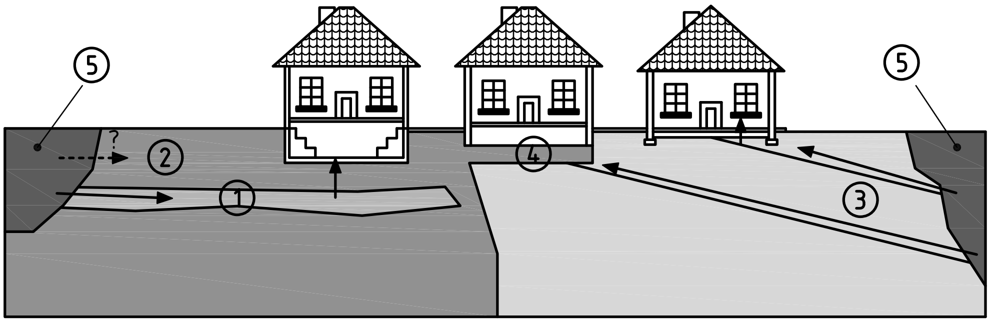
Figure 4 **Example design conceptual site model cross sections**



a) Examples of on-site sources of gas below buildings

Key	**Sources**		**Pathways**
1	Shallow mineworks	Ⓐ	Shafts, adits or other openings to mine workings
2	Deeper areas of made ground, or landfill, infilled railway cuttings	Ⓑ	Fractured rock
3	Shallow made ground	Ⓒ	Soil or rock above mine workings if it is sufficiently permeable to allow gas to migrate to surface
4	Shallow infill ponds	Ⓓ	Pathway only exists if soil above peat is sufficiently permeable to allow gas to migrate to the surface
5	Peat layers or layers of other organic material	Ⓔ	Migration via stone columns or around some types of piles
6	Alluvium, chalk or other natural soils		

b) Examples of off-site sources of gas migrating to below buildings



Key

①	More permeable layers (e.g. sand layers in glacial till)
②	Intervening strata, if soil is sufficiently permeable to allow gas migration
③	Migration in fractures or bedding in rock
④	Impermeable ground beneath building could prevents gas reaching surface
⑤	Landfill

NOTE With nearby landfills, the potential for gas migration depends on a number of factors, including:

- *design and operation of the landfill (presence of liners, permeability of capping layer, gas extraction system in operation, whether it is continuous or not); and*
- *type of waste and age of landfill.*

6 Process for ground gas characterization and hazard assessment

6.1 Risk assessment for ground gases

Before integral protective measures for buildings can be designed, an appropriate risk assessment should be carried out to decide:

- whether there is a potentially hazardous situation; and
- what the magnitudes of associated risks are.

NOTE 1 Guidance on how to conduct risk assessment can be found in CIRIA C665 [6].

NOTE 2 Use of fault tree analysis can help to identify critical states including what might go wrong. Guidance on fault tree analysis is provided in CIRIA Report 152 [7] and the Ground Gas Handbook [4].

NOTE 3 Ground gas characterization and hazard assessment are the initial parts of the risk assessment process. The subsequent stages are the analyses of source pathway receptor linkages.

*NOTE 4 Risk assessment results are only reliable if data and other information available about the site are sufficient in terms of quality, quantity and appropriateness (see **5.1**).*

Any uncertainty should be reflected in the design of the gas protection system.

NOTE 5 Information on the sources, properties and the hazards presented by carbon dioxide and methane is provided in BS 8576:2013, Annex D. The information includes an indication of the magnitude of the hazards in relation to concentrations and the control limits for various situations current at the time BS 8576:2013, Annex D was prepared.

Risk assessment and all design decisions should be documented and reported (see Clause **8** for further information and guidance on documenting and reporting).

6.2 Methodologies for ground gas characterization

*COMMENTARY ON **6.2***

The scope and nature of gas protection measures required may be determined by:

- *an empirical, semi-quantitative approach; and/or*
- *a detailed quantitative assessment approach.*

6.2.1 Empirical, semi-quantitative approaches

6.2.1.1 Empirical approach using gas monitoring data

*COMMENTARY ON **6.2.1.1***

*The empirical, semi-quantitative approach most commonly used is described in detail in **6.3**. It involves the use of a conceptual site model and monitoring data collected from gas monitoring standpipes installed in the ground.*

When this approach is used there should be sufficient site investigation information available to define the conceptual site model and sufficient gas monitoring measurements (see **5.1** and **5.4**). This approach derives an appropriate GSV, or several GSVs if a site is zoned. The GSV should then be used to select an appropriate CS for design, which is then used to inform the choice of protective measures (see Clause **7**).

NOTE The method is empirical because it is based on an assumption directly relating gas monitoring standpipe emission measurements to future gas emissions from a fixed volume of ground around the standpipe. The method is based on judgement and experience which has been shown to yield practical and reliable outcomes. Because of the empirical assumption of the method, the boundaries between CSs as defined by GSVs in Table 2 are also empirical.

6.2.1.2 Empirical approach using TOC

*COMMENTARY ON **6.2.1.2***

Sometimes where the gas source is made ground with low organic content it might be possible to adopt an alternative empirical approach that uses the conceptual site model, the TOC content of the strata identified as the gas source(s) and observations on the nature of the natural or made ground soil materials in the gas source(s).

The TOC approach should only be used when the conceptual site model indicates a very low to moderate potential gas hazard; such an approach is described in RB17 [1]. This method should not be used to assess coal workings, or sites with off-site gas sources or materials associated with active or recent waste disposal sites.

This alternative approach needs a carefully planned and executed investigation strategy and should not be applied retrospectively to an investigation that has been completed and which did not take the intention to apply the method into account in its design.

NOTE Annex D provides informative guidance on the application of such an approach.

6.2.2 Detailed quantitative assessment approach

Detailed quantitative assessment of ground gas emission and its effects should involve one or more of the following:

- gas generation and migration models;
- flow models to estimate surface emission rates (both advection and diffusion);
- numerical models to estimate migration and surface emission rates;
- models to assess the potential for hazardous gases to accumulate beneath or within buildings;
- fault tree analysis (or other quantitative risk assessment).

If the detailed quantitative assessment approach is used it should be supported by sufficient data and a robust conceptual site model.

*NOTE Recommendations on undertaking a detailed quantitative approach are given in **6.4**.*

6.3 Characterization using conceptual site model and gas monitoring data

*COMMENTARY ON **6.3***

This sub-clause sets out an empirical semi-quantitative method of assessment of hazards from permanent ground gases. It also sets out how the data collected during site monitoring visits that measure hazardous gas emissions from specific monitoring points is assessed and used to designate a GSV that represents the gas hazard present at the whole site (or GSVs for different zones of a site if zoning is fully supported by a developed conceptual site model and is not just based on gas monitoring data).

The process set out represents good practice and is based on CIRIA C665 [6], NHBC Guidance on evaluation of development proposals on sites where methane and carbon dioxide are present [8] and the Ground Gas Handbook [4]

6.3.1 General

*COMMENTARY ON **6.3.1***

The development of the GSV for the site or the zone follows a process in which:

- *borehole hazardous gas flow rates are calculated for each borehole standpipe for each monitoring event (see **6.3.3**) and included in a database;*
- *the reliability of the measured gas flow rates and concentrations is assessed taking into account borehole construction, etc (see **6.3.4** and **6.3.5**);*
- *decisions are made as to whether to use peak gas flow rates or steady-state rates in each calculation (see **6.3.6**);*
- *decisions are made about how to deal with any temporal or spatial shortages in the data (see **6.3.7.3**);*
- *a decision is made about whether the site might be zoned or not (see **6.3.7**); and*
- *judgements are made about what GSV to use for design purposes taking all relevant information into account.*

The designation of GSV should be made after consideration of the available monitoring data (**6.3.5** and **6.3.6**) and all other relevant aspects of an adequate conceptual site model and with knowledge of the development's sub-structure and foundation arrangement.

The presence of significantly elevated concentrations of methane or carbon dioxide with zero flow rates should be assessed and not dismissed. Even if all the monitoring indicates no gas emissions, an assessment should be made about whether or not different atmospheric or groundwater conditions might have led to measurable flows, whether any significant diffusive flow from the ground might occur, or whether typically lower pressures within buildings might pose a risk to the building development.

NOTE 1 Numerical modelling can be used to assess diffusive flows.

NOTE 2 Application of characterization using degradable organic fraction (see Annex D) might also help decision making, where the source is a relatively thin layer of made ground.

6.3.2 Gas monitoring data

*COMMENTARY ON **6.3.2***

Good practice gas monitoring provides field data that includes initial readings of gas concentration and gas flow, and subsequent data at time periods commonly recorded at 15 seconds, 30 seconds, 45 seconds, and so on until a steady state is achieved. An appropriate assessment of this field data is an important part of assessing gas hazards and when progressing from calculation of Q_{hg} (L/h) values for each location and each monitoring round toward derivation of an appropriate GSV (L/h) for the site or zone.

When taking measurements the initial flow reading (when the gas tap is first opened) might record a peak gas flow that is not sustained, and which reduces to a low flow or even falls below the instrument's limit of flow detection within the first 60 to 90 seconds.

Sufficient gas monitoring data should be collected in accordance with BS 8576. This data should be consistent with the sources of gas and migration pathways identified at the site being assessed.

6.3.3 Zoning of sites

Review of the data might suggest that a large site should be separated out into a number of separate zones. Sites should be zoned only where there is a clear reason for variations in gas monitoring results (e.g. different geology). The reasons for zoning a site should be clearly stated. Sites should not be zoned only on the basis of variations in gas monitoring data, unless clear trends, compatible with the conceptual site model, are established, such as sometimes occur with increasing distance from a landfill source adjacent to a large development site.

6.3.4 Calculation of borehole hazardous gas flow rate – Q_{hg}

The following gas monitoring data should be used to calculate the borehole hazardous gas flow rate (Q_{hg}):

a) measured ground gas concentrations expressed as percentage-by-volume of each hazardous ground gas being considered (methane and carbon dioxide); and

b) measured borehole flow rate, i.e. volume of total gas flow (of all gases present) being emitted from the monitoring point, q, expressed in litres per hour (L/h).

The maximum concentration recorded during the monitoring event should be used, unless the use of lower values can be justified, together with steady state values of gas flows.

NOTE 1 q may be measured in other volume per time period units, depending on the measuring method or flow pod being used, but needs to be converted to litres per hour for use in the equations that follow. The difference between flow rates measured by various instruments is covered in BS 8576:2013.

The borehole Q_{hg} (in L/h) should be calculated for each monitoring location and each monitoring event using the following (for each hazardous gas):

$$Q_{hg} = q\left(\frac{C_{hg}}{100}\right) \tag{1}$$

where:

q is the measured flow rate (in litres per hour) of combined gases from the monitoring standpipe.

C_{hg} is the measured hazardous gas concentration (in percentage volume/volume).

NOTE 2 In equation (1), the measured hazardous gas concentration C_{hg} is expressed as a percentage (%), i.e. as parts per hundred.

NOTE 3 As an example, if a total borehole flow of 6 L/h is measured, and of that total flow (of mixed gases) 10% is methane, then the flow of methane gas (i.e. the borehole Q_{hg} for methane – Q_{hgCH4}) is 0.6 L/h (of methane), calculated as:

$$\begin{aligned} Q_{hg}CH_4 &= 6 \times \frac{10}{100} \\ &= 0.6 \end{aligned}$$

i.e. 0.6 L/h of methane is being emitted, mixed with a flow of 5.4 litres of other gases.

If 25% of the total flow (of mixed gases) is carbon dioxide, then similarly the borehole Q_{hg} for carbon dioxide is 1.5L/h (of carbon dioxide) calculated as:

$$Q_{hg}CO_2 = 6 \times \frac{25}{100}$$

$$= 1.5$$

i.e. 1.5 L/h of carbon dioxide being emitted from that borehole, on that monitoring event, mixed with the other gases.

If a gas borehole flow is not detected, it should be assumed that it is at the detection limit of the equipment used for the purpose of this calculation.

If a negative flow is recorded it should not automatically be discounted. Rather, an assessment of whether, under different temporal conditions, a similar positive out-flow of gas could occur should be undertaken, consistent with development of the conceptual site model. Only when the reason for the negative value is reasonably understood, and a positive flow can be credibly ruled out, should a negative value be discounted.

6.3.5 Reviewing the database

The accumulated database of calculated hazardous gas flow rates should be reviewed on completion of each successive monitoring round taking account of the gas regimes anticipated, consistent with the conceptual site model. Aspects considered in the review process should include:

- the monitoring response zones, i.e. whether the response zone and location are designed to be (and are likely to be) representative of the source, pathway or receptor;
- the atmospheric pressure trends; and
- differential borehole pressure and groundwater level at the time, and atmospheric pressure and weather conditions, preceding and at the time of the monitoring event

NOTE 1 Waterlogged or frozen ground surfaces might affect the migration/venting of gases during such monitoring events.

The database should be designed to enable data representative of the source, and/or pathway and/or receptor (as appropriate to each specific development) to be clearly identified and understood.

NOTE 2 Monitoring point specific Q_{hg} *can be usefully visualized on plan and section views. Colour coding can aid such 3D spatial understanding of the gas regime, or regimes, that are present. Such presentation can be extended to assess temporal variability.*

6.3.6 Combining field data

When assessing how to combine the field data to aid derivation of an appropriate GSV, the following factors should be taken into account:

- the spatial adequacy of the monitoring locations compared to the variability of the underlying ground conditions;
- the relative position of the standpipe response zone and the groundwater table;
- the range of temporal atmospheric and groundwater conditions (including tidal if relevant) at which measurements were recorded; and
- atmospheric pumping, especially where a sudden fall in atmospheric pressure occurs.

The response zone of the gas monitoring standpipe should be wholly or partly above groundwater level to provide valid data for the guidance that follows.

NOTE 1 Gas standpipes with flooded response zones might exhibit measurements of elevated methane or carbon dioxide. This could be due to dissolved gases or presence of biodegradable material in the groundwater.

If water is present above the top of the slotted section of the gas standpipe, any peak flow recorded is likely to be due to a build-up of pressure caused by rising water trapping the gas within the solid section of pipe; in this case, the initial peak flow is not representative of the rate of gas generation within the ground, and new, better designed standpipes should be installed and decisions made about whether to carry out further monitoring from the existing installation.

6.3.7 Derivation of GSVs

6.3.7.1 General

The designation of GSV should be made by inspection of all the data based on the conceptual site model for the situation with the development's sub-structure and foundations in place.

NOTE 1 Adopting a GSV based on Q_{hg} calculated from peak flow measurements might result in a disproportionately high gas hazard prediction, and assignment of an over-precautionary CS.

NOTE 2 Examples of how monitoring data is considered to derive a GSV are given in Annex E.

Where a development is to be built directly on or very close to the source of gas, then the Q_{hg} adopted as the site or zone GSV should be based on gas measurements of the source. For a development off-set from a source, an assessment of the degree of hazard reduction afforded by the pathway between the source and the receptor should be made.

NOTE 3 If the source has been monitored and is at some distance off-set from the development, then selection of the GSV based on an application of the Q_{hg} obtained from the source is inappropriate.

A similar form of assessment of source hazard reduction should be made if the source is organic degradable material (e.g. peat) within an alluvial sequence that is conceptualized as being capable of supporting a reservoir of gas, but where the development above is protected to some degree by a lower permeability strata. In this case the alteration to the pathway that the building's foundation solution might incur should also form a key part of the assessment.

6.3.7.2 Representative and comprehensive data set

Where the dataset is representative and comprehensive, the GSV should be the maximum Q_{hg} measured for all the monitoring events. The data set should only be considered representative and comprehensive if it captures temporal variation.

A decision should be made to determine if peak or steady state maximum readings are to be used, taking into account the conceptual site model and the acute one-off nature of the risk. Data recorded at all the other gas monitoring locations should also be taken into account.

6.3.7.3 Temporally or spatially limited data sets

If the data set is temporally or spatially limited, peak or maximum steady state data can be combined from more than one monitoring standpipe location and different monitoring rounds, for each gas source; however, before doing so a decision should be made about the need to collect further monitoring data in preference. If further data is not collected then the GSV should be derived as the worst case, see **6.3.7.4.**

NOTE The purpose is to derive a GSV that captures known temporal variation and also seeks to account for a plausible data combination, that the more limited dataset has not captured, and to derive a GSV that is suitably precautionary in principle, to take account of the data set limitations.

6.3.7.4 Worst case check

Irrespective of the apparent comprehensiveness of the dataset, the plausible worst case condition should be calculated for each hazardous gas by multiplying the maximum recorded flow in any standpipe in that strata (and zone) with the maximum gas concentration in any other standpipe in that strata (and zone), but discounting any peak instantaneous flows and negative flows that have been judged to be unrepresentative of a possible worst case.

If this worse case check indicates that a greater hazard could reasonably exist, then either this worst case Q_{hg} should be adopted as the GSV, or further monitoring should take place to provide evidence that the worst case should not be used. To adopt the worst case Q_{hg} as the GSV, the assessor should be confident that to do so is prudent and reasonable and does not result in unnecessarily conservative protection of the development. The basis for decisions should be set out clearly and justifications stated.

NOTE Sensitivity analysis can inform the decision to undertake more monitoring, or to adopt the precautionary principle. If adoption of a precautionary worst case Q_{hg} *as the GSV, in lieu of additional monitoring might have serious construction implications for the development, then collection of an improved dataset is prudent. Conversely, where the additional protection is not practical to apply, then adopting a precautionary approach is appropriate.*

6.3.8 Characteristic gas situation (CS)

*COMMENTARY ON **6.3.8***

Trace permanent gases might also be present at much lower concentrations than those of methane and carbon dioxide. The site classification and design of protection measures based on methane and carbon dioxide flows might be adequate to provide protection against the acute effects from trace permanent gases, but a formal risk assessment is likely to be needed. The human health risk assessment might indicate that remediation to deal with trace gases or vapours is needed in addition to any building ground gas protection measures. The human health risk assessment might also need to include a consideration of the emissions from any under floor venting system to the ambient air around the building.

The CS should be determined from the adopted GSV (see **6.3.2** to **6.3.7)** and the ranges given in Table 2; a CS for both methane and carbon dioxide should be determined.

NOTE See Annex F for examples of the assignment of a CS by site characteristic GSV.

6.4 Quantitative assessment of gas risk to characterize a site

A detailed quantitative assessment of gas emissions should be carried out in appropriate situations, such as where sites have moderate to high hazards, where buildings have complex foundations, and where the approach described in **6.3** suggests an over-conservative assessment of risk posed by the presence of gas in the ground.

*NOTE 1 The different types of models that can be used are explained in **6.2.3**. These more detailed analyses are used to estimate the flow of gas through and from the ground.*

The models in **6.2.2** are based on fluid flow through the ground by advection and diffusion and should be compared to gas monitoring data wherever possible, with sensitivity analyses undertaken.

Table 2 **CS by site characteristic GSV**

CS	Hazard potential	Site characteristic GSV [A)] L/h	Additional factors
CS1	Very low	<0.07	Typically <1% methane concentration and <5% carbon dioxide concentration (otherwise consider an increase to CS2)
CS2	Low	0.07 to <0.7	Typical measured flow rate <70 L/h (otherwise consider an increase to CS3)
CS3	Moderate	0.7 to <3.5	–
CS4	Moderate to high	3.5 to <15	–
CS5	High	15 to <70	–
CS6	Very high	>70	–

[A)] The figures used in this column are empirical.

NOTE The CS is equivalent to the characteristic GSV in CIRIA C665 [6].

NOTE 2 The results from the models can be used to determine the scope of gas protection measures needed for a building and to design any necessary underfloor ventilation.

NOTE 3 This approach is of particular use where gas migrates through the ground from a source adjacent to the site (e.g. where landfill gas migration occurs).

NOTE 4 Further information on detailed quantitative risk assessment is provided in the Ground Gas Handbook [4].

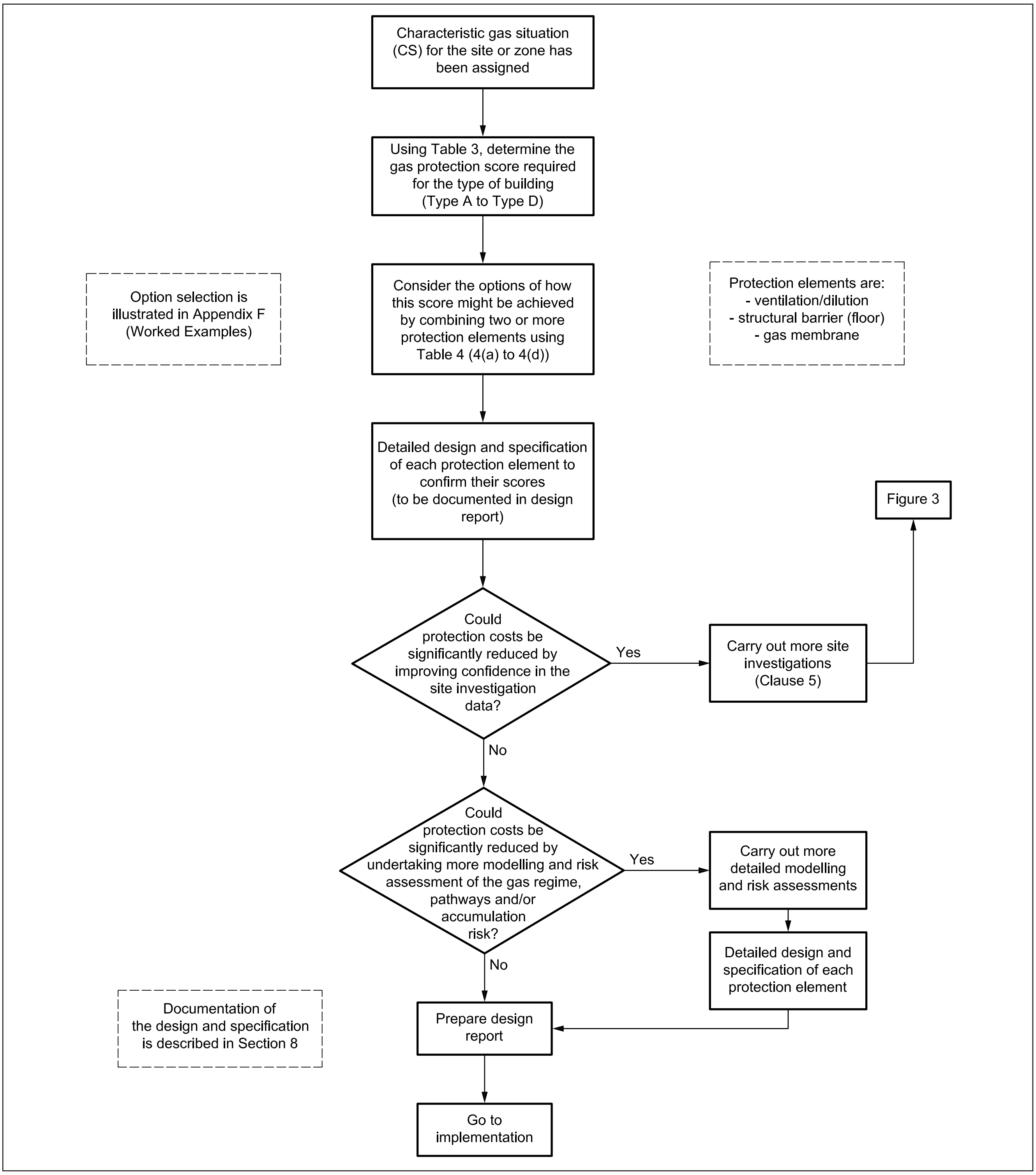
7 Solutions choice and detailed design

7.1 Approach

Appropriate gas protection measures should be selected based on the CS using the steps illustrated in Figure 5 and described in **7.1**, unless the protective measures are designed using quantitative modelling methods (see **6.4**).

NOTE 1 Guidance on radon and VOCs is given in Annex G and Annex H. These annexes provide valuable information to designers of gas protection systems for methane and carbon dioxide at sites which might also need protection against these gases.

Figure 5 **Solutions choice flow chart**



The construction and use of the building, together with the control of future structural changes to the building and its maintenance (the building's management) should be assessed, since potential risks posed by ground gases are strongly influenced by these factors. The assessment should lead to the categorization of the building as a whole, or each different part of the building, into one of four building types: Type A, Type B, Type C or Type D.

New buildings should be categorized in accordance with Table 3 and the descriptions that follow.

Table 3 **Building types**

	Type A	Type B	Type C	Type D
Ownership	Private	Private or commercial/ public, possible multiple	Commercial/ public	Commercial/ industrial
Control (change of use, structural alterations, ventilation)	None	Some but not all	Full	Full
Room sizes	Small	Small/ medium	Small to large	Large industrial/ retail park style

- **Type A building**: private ownership with no building management controls on alterations to the internal structure, the use of rooms, the ventilation of rooms or the structural fabric of the building. Some small rooms present. Probably conventional building construction (rather than civil engineering). Examples include private housing and some retail premises.
- **Type B building**: private or commercial property with central building management control of any alterations to the building or its uses but limited or no central building management control of the maintenance of the building, including the gas protection measures. Multiple occupancy. Small to medium size rooms with passive ventilation of rooms and other internal spaces throughout ground floor and basement areas. May be conventional building or civil engineering construction. Examples include managed apartments, multiple occupancy offices, some retail premises and parts of some public buildings (such as schools, hospitals, leisure centres) and parts of hotels.
- **Type C building**: commercial building with central building management control of any alterations to the building or its uses and central building management control of the maintenance of the building, including the gas protection measures. Single occupancy of ground floor and basement areas. Small to large size rooms with active ventilation or good passive ventilation of all rooms and other internal spaces throughout ground floor and basement areas. Probably civil engineering construction. Examples include offices, some retail premises, and parts of some public buildings (such as schools, hospitals, leisure centres and parts of hotels).
- **Type D building**: industrial style building having large volume internal space(s) that are well ventilated. Corporate ownership with building management controls on alterations to the ground floor and basement areas of the building and on maintenance of ground gas protective measures. Probably civil engineering construction. Examples are retail park sales buildings, factory shop floor areas, warehouses. (Small rooms within these style buildings should be separately categorized as Type B or Type C).

NOTE 2 Type A buildings are those where the risk of failure of the gas protection measures is likely to be most significant to the safety of the occupants and Type D buildings are those where this same risk is likely to be least significant.

From the design CS and the type of building (A, B, C or D) the minimum level of gas protection (score) in the range 0 to 7.5 should be determined in accordance with Table 4.

Table 4 **Gas protection score by CS and type of building**

CS	**Minimum gas protection score (points)**			
	High risk		Medium risk	Low risk
	Type A building	Type B building	Type C building	Type D building
1	0	0	0	0
2	3.5	3.5	2.5	1.5
3	4.5	4	3	2.5
4	6.5[A)]	5.5[A)]	4.5	3.5
5	— [B)]	6.5[A)]	5.5	4.5
6	— [B)]	— [B)]	7.5	6.5

[A)] Residential buildings should not be built on CS4 or higher sites unless the type of construction or site circumstances allow additional levels of protection to be incorporated, e.g. high-performance ventilation or pathway intervention measures, and an associated sustainable system of management of maintenance of the gas control system, e.g. in institutional and/or fully serviced contractual situations.

[B)] The gas hazard is too high for this empirical method to be used to define the gas protection measures.

NOTE 3 The NHBC has published guidance [8] for use on residential developments, which utilizes an alternative classification ("traffic light") system. This guidance typically applies to Type A buildings utilizing beam and block floor constructions with clear void ventilation. The design choice variables are limited to decisions relating to the membrane specification and verification recommendations (see Table 7). Designers utilizing this system would therefore need to refer to the NHBC [8] to assess compliance for specific recommendations.

When the minimum gas protection score has been determined for the building as a whole, or for each part of the building, then a combination of two or more of the following three types of protection measures should be used to achieve that score:

- the structural barrier of the floor slab, or of the basement slab and walls if a basement is present;
- ventilation measures; and
- gas resistant membrane.

NOTE 4 The method of selecting the combination of these types of protection measures for a particular building is given in ***7.2****.*

Once the types of protection measures have been decided, the detailed design and specification of the measures should be undertaken (see **7.3**).

NOTE 5 In some cases, the designer might be of the opinion at this stage that the extent of the protection measures is potentially more than is needed, because of limitations in the scope of the site investigation [these limitations having led to a more conservative GSV and CS than is likely from the conceptual site model (see ***6.3.7.2*** *and* ***6.3.7.3****)]. In this case, further site investigation could be carried out to check the GSV. Only if there is sufficient time to carry out additional site investigation and gas monitoring would this step be useful.*

The detailed design and specification of the protection measures should be recorded in a design report (see **8.3**).

7.2 Selection of appropriate protection measures

7.2.1 General

Having determined the minimum gas protection score for the building, or each different part of the building, from Table 4, an element or combination of elements should be chosen from Table 5, Table 6, and Table 7 with a combined score achieving the minimum recommended gas protection. No more than one element of each type (i.e. from each table) should be combined to achieve the recommended gas protection score.

The gas protection system should consist of at least two different elements; for example, a barrier element with either a membrane or a ventilation or dilution element (or both). The elements work independently and collaboratively, and a single element should not be used because there would be no redundancy to allow for defects in the component.

NOTE For low sensitivity buildings on low risk sites it might sometimes be possible to rely solely on a membrane or slab; for example, where internal ventilation provides secondary protection.

The selection process should be transparent in that all interested parties can see the approach taken, understand the various steps and decisions made, and be confident that a robust risk-assessed solution has been designed and installed commensurate with the construction and site constraints.

Where the CS is CS4 or higher, the site should have a comprehensive assessment done to support the adequacy of the proposed protection measures. Reliance should not be placed solely on Table 5, Table 6 and Table 7.

7.2.2 Structural barrier

The first step in the methodology should be the assessment of the gas protection score of the structural barrier, since the construction of the floor slab has usually already been decided at the time the gas protection measures are being designed.

NOTE The floor slab design, and any basement design, are usually determined by geotechnical and constructability factors.

The common types of floor slab and substructure design and their relative performance as a structural barrier to ground gas ingress are described in Annex A. The structural barrier score should be assigned in accordance with Table 5; further guidance is given in Annex A.

Table 5 **Gas protection scores for the structural barrier**

Floor and substructure design (see Annex A)	**Score** A)
Precast suspended segmental subfloor (i.e. beam and block)	0
Cast in situ ground-bearing floor slab (with only nominal mesh reinforcement)	0.5
Cast in situ monolithic reinforced ground bearing raft or reinforced cast in situ suspended floor slab with minimal penetrations	1 or 1.5 B)
Basement floor and walls conforming to BS 8102:2009, Grade 2 waterproofing C)	2
Basement floor and walls conforming to BS 8102:2009, Grade 3 waterproofing C)	2.5

A) The scores are conditional on breaches of floor slabs, etc., being effectively sealed.

B) To achieve a score of 1.5 the raft or suspended slab should be well reinforced to control cracking and have minimal penetrations cast in (see **A.2.2.2**).

C) The score is conditional on the waterproofing not being based on the use of a geosynthetic clay liner waterproofing product (see **C.3**, Note 4).

When practical, utilities should enter the building above floor level with any conduit or meter housing being properly vented outside of the building.

7.2.3 Ventilation measures

Ventilation protection measures should be one of the following five types, and points can only be scored for one of these measures:

a) pressure relief pathway only (no effective dispersal layer);

b) passive dispersal layer;

c) active dispersal layer (fan suction);

d) active positive pressurisation (air blanket); and

e) ventilated basement substructure present.

NOTE 1 For Type A buildings active ventilation measures are inappropriate.

The applicability and design of ventilation protection measures and selection of an appropriate score should be carried out in accordance with Annex B.

A ventilation protection measure should have a design with a defined level of performance and supporting dilution calculations. Recommendations on both design and performance criteria for methane and carbon dioxide are provided in Annex B and should be followed.

NOTE 2 There are a wide range of different media used to form the gas dispersal layer for both passive and active systems, and more are likely to be developed.

Designs should use a gas permeability value which is representative of the media in its as-built condition, taking into account the continuity of the media beneath the floor slab, loss of volume due to compression, the pressure differences that apply across the media, and head losses in the terminals.

NOTE 3 The types of media include expanded polystyrene void formers, geocomposite void formers, no (or low) fines gravel, and drains formed by perforated pipes or geocomposite strips.

NOTE 4 The continuity of the media beneath the floor slab might be interrupted by ground beams, pile caps, edge beams and other intrusions extending below the level of the media blanket, which might significantly reduce the effectiveness of the dispersal layer.

NOTE 5 The effective volume of the gas dispersal layer might be reduced by its placement on a soft layer (for example, sand blinding) which reduces its gas permeability and dispersal effectiveness. The effective volume would also be reduced, or eliminated, if the media became flooded with groundwater or clay heave occurred.

NOTE 6 The performance of passive systems can be significantly affected by the number and type of side ventilation terminals. Common side terminals are airbricks, low level vents and high level vent stacks. Guidance on side ventilation is given in Annex B.

In certain circumstances passive ventilation is difficult to achieve, such as where there is a very large building footprint, basement or complex ground beam arrangement. In such cases, a system might be designed as “pressure relief” alone and this should be detailed accordingly in the design. As a bare minimum all gas protection systems should include at least pressure relief (a preferential pathway to atmosphere) for gases which might otherwise build up under the building footprint.

The gas protection scores applicable to different types of passive and active ventilation systems are given in Table 6. The selected score should be assigned in accordance with Annex B and be compatible with gas dispersal performance of the system.

Table 6 **Gas protection scores for ventilation protection measures**

Protection element/system	Score	Comments
(a) Pressure relief pathway (usually formed of low fines gravel or with a thin geocomposite blanket or strips terminating in a gravel trench external to the building)	0.5	Whenever possible a pressure relief pathway (as a minimum) should be installed in all gas protection measures systems. If the layer has a low permeability and/or is not terminated in a venting trench (or similar), then the score is zero.
(b) Passive sub floor dispersal layer:		Performance criteria for methane and carbon dioxide are shown in Figure B.6 and Figure B.7, respectively. The ventilation effectiveness of different media depends on a number of different factors including the transmissivity of the medium, the width of the building, the side ventilation spacing and type and the thickness of the layer. The selected score should be assigned taking into account the recommendations in Annex B. Passive ventilation should be designed to meet at least "good performance", see Annex B.
Very good performance:	2.5	
Good performance:	1.5	
Media used to provide the dispersal layer are: • Clear void • Polystyrene void former blanket • Geocomposite void former blanket • No-fines gravel layer with gas drains • No-fines gravel layer		
(c) Active dispersal layer, usually comprising fans with active abstraction (suction) from a subfloor dilution layer, with roof level vents. The dilution layer may comprise a clear void or be formed of geocomposite or polystyrene void formers	1.5 to 2.5	This system relies on continued serviceability of the pumps, therefore alarm and response systems should be in place. There should be robust management systems in place to ensure the continued maintenance of the system, including pumps and vents. Active ventilation should always be designed to meet at least "good performance", as described in Annex B.
(d) Active positive pressurization by the creation of a blanket of external fresh air beneath the building floor slab by pumps supplying air to points across the central footprint of the building into a permeable layer, usually formed of a thin geocomposite blanket	1.5 to 2.5	This system relies on continued operation of the pumps, therefore alarm and response systems should be in place. The score assigned should be based on the efficient "coverage" of the building footprint and the redundancy of the system. Active ventilation should always be designed to meet at least "good performance".
(e) Ventilated car park (floor slab of occupied part of the building under consideration is underlain by a basement or undercroft car park)	4	Assumes that the car park is vented to deal with car exhaust fumes, designed to *Buildings Regulations 2000, Approved Document F* [9].

7.2.4 Membrane

Gas resistant membranes should be:

a) sufficiently impervious to methane and carbon dioxide;

b) capable after installation of providing a complete barrier to the entry of the relevant gas.

c) sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions;

d) sufficiently strong to withstand in service stresses (e.g. due to ground settlement if placed below a floor slab);

e) sufficiently strong to withstand the installation process and following construction activities until covered (e.g. penetration from steel fibres in fibre reinforced concrete, penetration of reinforcement ties, tearing due to working above it, and dropping tools); and

f) chemically resistant to degradation by other contaminants that might be present.

NOTE 1 A methane gas transmission rate of <40.0 ml/day/m^2/atm (average) for sheet and joints (tested in accordance with the manometric method in BS ISO 15105-1) is usually considered sufficient.

NOTE 2 Guidance on the relevant properties relating to a), c) and e) is provided in CIRIA C748 [10].

There are many gas resistant membrane types available and membrane choice should be made according to the resistance of the material to the passage of the challenge gas and the resistance to site damage during and after installation in the designed position. The designer specifying the membrane should consider the combination of a particular membrane's properties to assess whether it is suitable in any given situation. The specified membrane and the reasons for its selection should be described in the design stage report (see **8.1**).

NOTE 3 Advice on membrane selection is given in Annex C.

NOTE 4 The installation and subsequent protection of the membrane are key factors in its performance. A poorly installed membrane cannot perform, however well detailed and irrespective of the performance of the material. Historically, reference has been made to verification and integrity testing without having any referenced documents against which to judge. The verification process is now described in CIRIA C735 [N1] and as such, confidence in the installed solution can be measured. The process removes the uncertainty of unqualified or inexperienced installation operatives by requiring a verification plan to be drawn up prior to the installation, with frequency and type of verification being dependent upon the qualifications of the installation operatives, site risk and design criteria.

A verification plan for the installation of the membrane should be part of the detailed design (see **8.3.2**).

NOTE 5 Current guidance on verification recommendations takes into account the risk of the overall design and confidence in its installation, and sets a frequency and level of verification appropriate.

A gas protection score (see Table 4) should only be assigned to a membrane which is formed of a material with suitably low gas permeability and which has been installed so it completely seals the foundation (including effective seals around all penetrations) and does not sustain damage from in-service stresses. The criteria which should be met to assign a gas protection score of two points is set out in Table 7.

Table 7 **Gas protection score for the gas resistant membrane**

Protection element/system	Score	Comments
Gas resistant membrane meeting all of the following criteria: • sufficiently impervious to the gases with a methane gas transmission rate <40.0 ml/day/m²/atm (average) for sheet and joints (tested in accordance with BS ISO 15105-1 manometric method); • sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions; • sufficiently strong to withstand in-service stresses (e.g. settlement if placed below a floor slab); • sufficiently strong to withstand the installation process and following trades until covered (e.g. penetration from steel fibres in fibre reinforced concrete, penetration of reinforcement ties, tearing due to working above it, dropping tools, etc); • capable, after installation, of providing a complete barrier to the entry of the relevant gas; and • verified in accordance with CIRIA C735 [N1]	2	The performance of membranes is heavily dependent on the quality and design of the installation, resistance to damage after installation and integrity of joints. For example, a minimum 0.4 mm thickness (equivalent to 370 g/m² for polyethelene) reinforced membrane (virgin polymer) meets the performance criteria in Table 7 (see **C.3**). If a membrane is installed that does not meet all the criteria in column 1 then the score is zero.

7.3 In-ground pathway intervention

A site which is impacted by migratory gases from an off-site source should be protected by pathway intervention methods, which, if successfully validated, could also remove the need for further protection.

The gas regime on the site should be fully characterized and include identification of potential pathways from the off site source.

NOTE 1 Methods of pathway intervention include simple vertical membrane installations, vent trenches, rows of stone columns, activated trenches and proprietary systems.

NOTE 2 For residential dwellings, management and maintenance is only acceptable where pathway intervention measures (e.g. venting trenches) are beyond the extent of the building(s), on or close to the boundary of the property in a position where access can be guaranteed.

7.4 Detailed design

Once the design measures have been selected in accordance with **7.2**, these should be developed into a detailed design supported by detailed drawings and specifications.

The detailed design should then be described in the design report (see **8.3**).

The person who has selected the design measures and whoever is preparing the detailed design should liaise during the development of the detailed design.

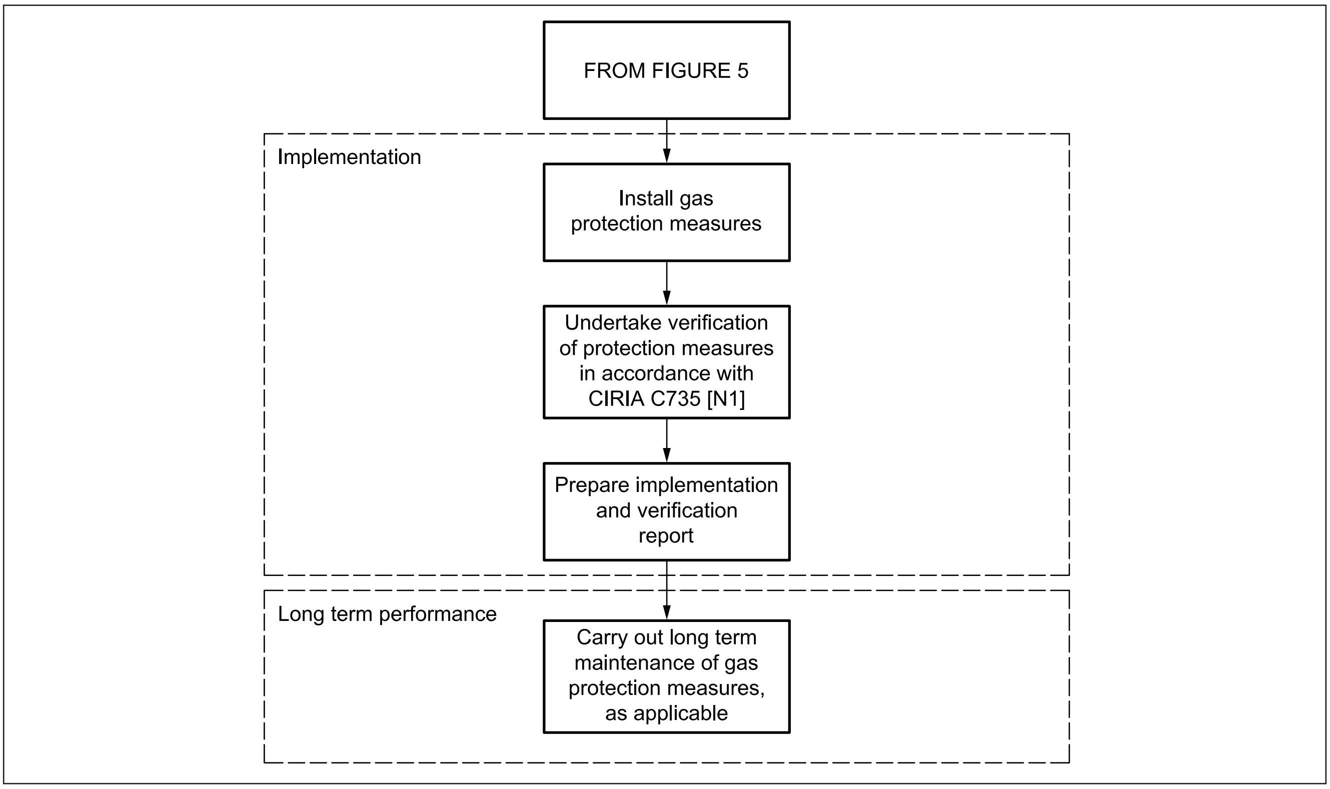
NOTE This consultation might result in a decision that the selected design measures cannot be implemented for practical reasons and consequently a rethink might be needed about what design measures are to be employed.

8 Implementation, verification and reporting

8.1 General

Figure 6 shows the steps that should be taken in the construction and on-site verification of the gas protection measures, documentation of the design and construction, and long term maintenance of the measures (if needed).

Figure 6 **Implementation stage**



The characterization of ground gas hazard at a site, the basis of the design of the gas protection measures, the installation of the measures and the verification inspections, monitoring and testing of the measures should be recorded in a report or series of reports, with design and as-built drawings. There can be substantial differences in report content depending upon the complexity of the ground gas regime, the sensitivity of the development, the nature of the gas protection measures adopted and the level of reassurance needed. However, the report should always adopt a formal structure and state whether it covers design, installation and/or verification aspects and includes all the necessary evidence to verify the adequacy and/or compliance of stated remedial objectives and design criteria.

To achieve this, the following given in Table 8 should typically be included within the design, installation and verification report(s).

NOTE 1 The reports are likely to be produced as separate documents but may be combined in a single document on completion of all relevant phases.

Table 8 **Information to be included in the design, installation and verification report**

Phase	**What to include**
All	Contents Summary Objectives Site conditions and characterization of the ground gas regime
Design	Construction and building related details Product design, product specifications and justification Recommended verification approach
Installation and verification	Description of the installation, including details of parties involved (i.e. installer, verifier) and guarantees offered Details of any deviation from the original design, and explanation and justification As-built construction drawings/schematic plans and product specifications Verification approach/methodology Quality assurance/verification evidence, including photographs, monitoring/test results and data gathered Details of communications held with regulatory bodies Conclusions, including future monitoring/management requirements and/or limitations of measures applied.

Reference should always be made to any specific requirements set by the regulator (e.g. via planning conditions and/or building control conditional requirements). The design parameters, specifications, justifications and method of verification should be approved in advance of works by the appropriate regulatory authority and relevant correspondence should be referenced and, where appropriate, included in an annex.

NOTE 2 Guidance on reporting and verification is set out in CLR11 [2], CIRIA C735 [N1] and Verification of Remediation of Land Contamination [11].

8.2 Site conditions and characterization of the ground gas regime

To design gas protection measures, a robust site characterization should be used to enable determination of the site gas regime with confidence. The person preparing the report should understand and discuss the findings of any previous field work and gas monitoring survey results, modelling and assessment. The text should provide the reader with a clear understanding of the ground gas regime and how it has been derived from the available evidence together with an outline understanding of the proposed development.

*NOTE See Clause **6** for the ground gas characterization and gas risk assessment process.*

8.3 Design phase

8.3.1 Construction and building related details

A designer/specifier of gas protection measures needs to be able to understand the gas risk assessment findings; however, an understanding of building related influences should also be acquired as these can significantly govern the design options and choices to be used for the gas protection measure. Construction and building related details, that can influence, or have influenced the design choices, should be fully detailed and implications discussed.

NOTE 1 Examples of construction and building related details are:

- *the sensitivity of the building, its size, shape and locality;*
- *the existence of below ground basements, under crofts and/or mechanical ventilation features;*
- *the floor slab type and its likely nature of construction;*
- *level threshold requirements and positioning;*
- *wall construction;*
- *the installers experience and knowledge of the designed system;*
- *the complexity (stability) of the ground conditions and drainage characteristics; and*
- *existence and frequency of complex detailing (e.g. stepped foundations, complex building shapes, and lift pits).*

NOTE 2 Energy efficiency and access considerations can significantly influence the design choice and ultimately the approach needed at the construction phase. For example, the width of the cavity wall, to achieve thermal insulation or level threshold access requirements under the building control regulations may require design of bespoke or flexible air vents which can adapt to the increased cavity widths or reduced elevation positioning.

8.3.2 Gas protection design, product specifications and justification

The gas protection design and product specifications should be clearly defined and justified.

Reference to the solution scores in Table 5, Table 6 and Table 7 should be provided to assist the design in terms of the basic recommendations and applicability of the overriding design approach, in relation to the gas regime determined.

Pre-construction drawings and construction notes should be included, where possible within an annex or the main text of the report.

NOTE 1 Refinements to the end design might be necessary, to accommodate last minute construction changes; for example, design and build schemes often might adopt last minute changes to construction methods or choices.

The designer should ensure that the report clearly details critical assumptions behind the design philosophy and identifies crucial design elements. The report should make it explicit that where construction proposals change, then the design should be re-checked to ensure compliance with the overall design objectives and, where appropriate, might need refinement.

To justify the venting design the designer/specifier should provide ventilation calculations to show that the ventilation capability of the proposed system achieves the design specification. The calculations and the justification for selected input parameters should be clearly reported.

NOTE 2 Recommendations to assist this process are given in Annex B.

NOTE 3 Venting calculations are particularly important for large span footprints, complex constructions, and/or where a combination of proprietary products is used. For simple structures, such as structures comparative with the NHBC "model house" (see [8]), or comparative with the design criteria as detailed in Passive Venting of Soil Gases Beneath Building, Guide for Design [12], the venting capability is usually deemed to comply and venting calculations may be unnecessary.

NOTE 4 Recommendations on ventilation modelling can be found in BS 5925. Useful advice is also provided in the Ground Gas Handbook [4].

In specifying the barrier design, the designer should clearly define the characteristics for the gas barrier and provide justifications; for example, a gas membrane barrier might need to achieve certain puncture resistance, where reinforced slabs or screeds are being adopted and/or where protection after the barrier's installation might be delayed.

Other important information that should be contained in the report includes:

- the severity of the gas regime and sensitivity of the land use;
- the membrane permeability characteristics for the critical gas of concern;
- whether or not the product is certified (i.e. does it hold CE marking, third party accreditation);

  NOTE 5 Attention is drawn to Regulation 7 of the Building Regulations 2010 [13] for schemes in England and certification might be a requirement for the approved inspector.

- laboratory test data;
- flexibility and tear resistance ranges;

  NOTE 6 This might be critical where settlement and/or where construction slab/wall movements are possible.

- component compatibility (particularly important for sealing components as some materials are not compatible with others);
- need (or not) for preformed sections or fabricated units;
- expectation of installer (i.e. experience and knowledge, which is usually dependent on the complexity of the detail, such as stepped foundations, complex building shapes and lift pits).

NOTE 7 The above list is not exhaustive or preclusive of the information to be included.

The designer needs to be aware of key considerations that are specific to the site requirements, and should detail critical design criteria as appropriate within the main text of the report.

8.3.3 Recommended verification approach

There are different verification approaches and testing tools available to demonstrate the quality of installed gas measures so an approach best suited to the needs of the individual scheme should be defined and selected.

NOTE Advice on verification approaches, tools and techniques can be found in CIRIA C735 [N1].

The proposed verification plan should be sufficiently detailed, within the main body of the report, together with the rationale for the recommended approach. Where regulatory conditions relating to the verification process have been applied, then the approach should be agreed in advance of works to ensure that proposals are acceptable.

Information pertinent to the verification plan should include:

- how, when and by whom the verification task/s should be carried out;

- compliance criteria (i.e. what constitutes a pass/fail);
- frequency of verification task/s;
- methodology;
- QA/QC requirements;
- how and when information should be reported;
- regulatory requirements; and
- contingency plan (i.e. what needs to be done if results fail to meet compliance criteria).

8.4 Installation and verification phase

The installation and verification report should present an accurate description of the measures actually applied and present the evidence gathered to confirm that installed measures are suitable for purpose.

As a minimum, the report should include:

- a description of any measures installed – this could be presented in textual form, as photographic records or by as-built construction drawings (any variations to the pre-construction design should be fully detailed and justification(s) presented);
- details of who installed the measures;
- details of who inspected or verified the installation/s and a description of how this took place, together with any constraints (i.e. areas that could not be inspected or tested) or other issues of uncertainty;
- verification test results, outcome of inspections and compliance data should be provided, either within the main text or as an annex to the report; and
- any defects identified, together with corrective actions and subsequent verification checks.

Where appropriate, the report content should also include:

- copies of regulatory correspondence/sign off;
- manufacturers' specifications, warranties and/or guarantees;
- personnel details (such as relevant qualifications); and
- maintenance requirements and/or limitations of the system.

In all circumstances, the report should provide a concluding comment about the suitability (or otherwise) of installed gas measures and include the name of the author, company details and date of issue.

Annex A (informative) Floor slab and substructure design

A.1 General

Gas protection measures normally require a number of separate elements or components that together create a composite and integrated system which adequately prevents ingress of ground gases. The ground floor slab and/or basement floor slab is usually one of these elements; the others are usually ventilation and/or a gas resistant membrane.

The design, form, construction and anticipated performance of a building's substructure might influence the physical characteristics and specification requirements for the impermeable/gas resistant membrane, which in turn might be influenced by the proposals for ventilation. Each of these elements contribute to the resistance to the passage of gas into the building so during the design stage consideration is given to the appropriate combination of these elements. This is to maintain their integrity during the construction stage and achieve satisfactory long term performance during the design life of the building.

Building substructures provide varying degrees of resistance to the passage of gas depending on their form but they are not sufficiently impervious to prevent complete gas ingress. For example, segmental ground floor construction methods such as suspended beam and block floors contain many joints and discontinuities. Such floor types provide significantly less resistance for ground gas ingress than well-constructed cast in-situ reinforced concrete raft foundations, which are monolithic with few joints. However, these are not completely impermeable and normally contain some cracking at a microscopic level. For low sensitivity buildings on low risk sites it might sometimes be possible to rely solely on a membrane or slab; for example, where internal ventilation provides secondary protection.

The guidance in this British Standard on the selection of protection measures is based on consideration of four typical classes of substructure:

- precast suspended segmental subfloors without and/or with bonded reinforced structural concrete topping (e.g. beam and block);
- cast in-situ ground bearing floor slab with mesh reinforcement for crack control constructed off a sound sub-base (e.g. traditional ground bearing floor slab);
- cast in-situ monolithic reinforced concrete ground bearing raft or suspended/semi-suspended cast in-situ reinforced concrete slab with minimal penetrations; and
- fully tanked basement (see BS 8102:2009, Grade 3 for further guidance).

To aid understanding and appreciation of the scoring in Table 5, and to assist in determining the appropriate design of gas protection measures, background on some common forms of construction and their associated influences in relation to ground gas protection is given in **A.2**, **A.3** and **A.4**.

A.2 Foundation and floor slab types

A.2.1 General

The foundation solution for a structure is developed by considering the type of building, its form and the loads it applies to the ground along with the ground conditions, groundwater regime, soil bearing capacity and settlement characteristics.

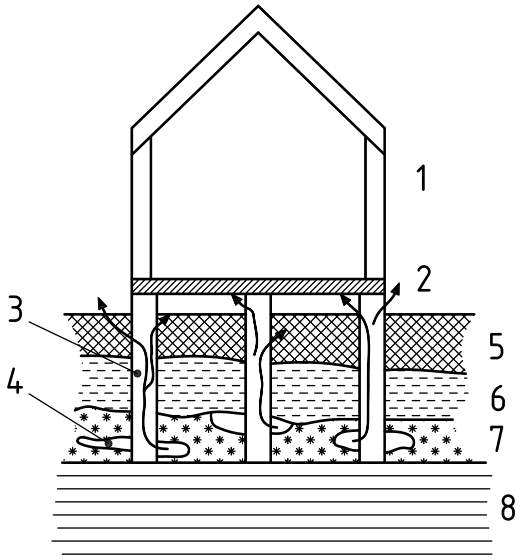
Foundations can be broadly divided into two categories.

- Shallow foundations which include strip footings, trench fill foundations, pad foundations, rafts and shallow basements. These are unlikely to have any significant direct impact on the underlying gassing regime in the ground.

- Deep foundations which include various types of piles and pile walls, diaphragm walls, vibro compaction and deep basements. These deeper foundation solutions can influence or change ground gas pathways and gas generation rates. This might be due to the creation or alteration of flow paths for existing ground gases or be the result of the introduction of oxygen at depth (e.g. in peaty soils) promoting the generation of ground gas.

The foundations adopted for a building can influence the generation of gas and/or the pathways through which the gas might move and thus impact on the gas protection measures required. This could be a result of changing the permeability of the underlying strata, possible changes to the groundwater regime and the creation of preferential pathways due to the proposed foundation solution (e.g. vibro stone columns, see Figure A.1). Assumptions made during initial gas risk assessments, including gas flow rates, are re-evaluated during the design of the foundations for the building.

Figure A.1 **Example of potential influence of vibro stone columns for gas migration**



Key

1	Dwelling	5	Made ground
2	Gas pathways	6	Clay
3	Vibro stone column	7	Peat
4	Gas pocket	8	Bedrock

A.2.2 Ground bearing ground floor structures

COMMENTARY ON ***A.2.2***

Where ground conditions are suitable, ground floors can be of solid concrete construction formed directly off the ground (i.e. ground bearing). Common forms of ground bearing floor slab are described in more detail in ***A.2.2.1, A.2.2.2*** *and* ***A.2.2.3****.*

A.2.2.1 Traditional ground bearing slabs

Where ground conditions permit, traditional ground bearing slabs are one of the most commonly used forms of construction in the UK for the formation of ground floors for habitable buildings.

Ground bearing slabs are typically constructed from a minimum of 100 mm of cast in-situ concrete with a nominal mesh reinforcement or fibre reinforcement to control shrinkage. When concrete is placed to form ground bearing slabs it is often tamped into position rather than vibrated and might be less dense than purpose designed reinforced concrete.

Ground bearing slabs are used where the ground and/or any infill can safely support the weight of the slab and the applied loads without undue settlement. A ground bearing slab is independent of the foundations and normally abuts any loadbearing walls. Insulation to satisfy thermal requirements might be incorporated above or below the concrete slab.

A.2.2.2 Raft foundations

Raft foundations are utilized in situations where poor ground conditions are present and the pressures applied to the soils by the building need to be kept as low as possible. They are designed as flat slabs in accordance with BS EN 1992.

Semi-rafts are normally constructed of traditional reinforced concrete with a minimum slab thickness of 150 mm incorporating reinforcement in the top and bottom faces with downstand beams designed to suit the ground conditions.

Some independently certified proprietary systems now utilize fibre reinforced concrete instead of traditional reinforcing bars. Raft foundation may incorporate insulation above or below the slab or use proprietary insulation pods.

A.2.2.3 Industrial floor slabs

Floor slabs of industrial buildings, such as warehouses and manufacturing premises, are typically formed of well reinforced ground bearing or suspended slabs. They are usually designed for minimal total and differential settlement and with widely spaced construction joints. Generally many fewer services enter through the floor slab than for residential or commercial use buildings. The combination of all these factors, together with the large inter-connected space of most or all of the building, provides a low gas risk situation. The key factor is the sealing of construction joints in the floor slab and sealing of all service entries through the floor slab.

A.3 Suspended ground floor construction

Suspended ground floor construction is frequently utilized in situations where the ground conditions are not suitable for ground bearing slabs and the loads from the building need to be transferred directly to the foundations. Suspended ground floors can be used with shallow or deep foundation solutions.

Suspended floors take various forms using in-situ concrete, precast concrete (e.g. beam and block or planks), lightweight steel joists or composite steel decking with concrete and timber.

Suspended or semi suspended floors constructed from reinforced dense cast in-situ structural concrete normally achieve low permeability as they contain relatively few construction joints and discontinuities. However, they be can be affected by various types of cracking for ground bearing floor structures.

Other forms of suspended floors (e.g. beam and block, and timber) provide significantly less resistance to the passage of ground gas, as they are made up of individual blocks/panels/joists with many gaps. As a consequence, the floor structure has high permeability.

The upper floor finish to precast concrete systems might offer the potential to provide a broadly continuous barrier but the effectiveness of this in resisting the ingress of gas depends on its construction. A dense concrete structural topping of adequate depth with appropriate mesh reinforcement to control shrinkage that is fully bonded to the top of the precast floor might significantly reduce the overall permeability for a beam and block floor.

The issue of gaps at floor/wall junctions is obviated by the use of suspended floor since the floor structure is built into the supporting structure. Service ducts and entries and other penetrations through ground bearing structures can provide pathways for gas entry if not properly sealed and need to be considered. Potential problems can sometimes be avoided by bringing services into the building above floor level (the service runs and entry pods or meter housings need ventilation).

A.4 Basements

Basements can be shallow (one storey) or deep (two storeys or more) and can be full, occupying the entire footprint of the building, or partial with only part of the structure below ground. Basement slabs are normally constructed from in-situ reinforced concrete and may be ground bearing slabs/rafts or supported on piles.

Walls to shallow basements can be constructed from a wide range of materials including plain masonry, reinforced masonry, mass concrete, reinforced concrete, precast concrete, various proprietary insulated and non-insulated formworks systems. For deep basements, walls are normally constructed from reinforced concrete or embedded retaining wall solutions such as diaphragm walls, contiguous pile walls, secant pile walls or interlocking driven sheet piling.

Every basement design takes into account the site-specific conditions including the groundwater regime. The two primary criteria for the design are normally:

- the structural design to support the vertical loads from the building superstructure and the lateral loads from the retained ground and groundwater; and
- the waterproofing protection system to prevent or control ingress of groundwater.

Guidance on methods of dealing with and preventing the entry of groundwater into basements is given in BS 8102:2009.

Table A.1 reproduces Table 2 from BS 8102:2009 which defines three grades of waterproofing protection.

Table A.1 **Grades of waterproofing protection**

Grade	Example of use of structure	Performance level
1	Car parks; plant rooms (excluding electrical equipment); workshops	Some seepage and damp areas is tolerable, dependent on the intended use. Local drainage might be unable to deal with seepage.
2	Plant rooms and workshops (which need a drier environment than Grade 1); storage areas	No water penetration acceptable. Damp areas tolerable; ventilation might be needed.
3	Ventilated residential and commercial areas including offices, restaurants and leisure centres	No water penetration acceptable. Ventilation, dehumidification or air conditioning necessary, appropriate to the intended use.

Risks associated with the groundwater regime are taken into account when selecting a water proofing system to achieve the required basement grade. The protection provided comprises one or more of the following types:

- **Type A**: barrier protection including bonded sheet membranes, liquid applied membranes, geosynthetic membranes, mastic asphalt membranes, cementitious multi-coat renders and slurries;
- **Type B**: structurally integral protection consisting of reinforced concrete designed as water resisting or with waterproof admixtures with appropriate waterstops to joints; and
- **Type C**: drained protection incorporating cavity drain systems to walls and floors to collect seepage.

As with other substructures solutions, the potential permeability of basements structures vary depending on the form and type of construction adopted, the frequency of joints, the occurrence of cracking and the presence of service penetrations and discontinuities.

Due to the variety of potential forms of construction for basements along with the wide range of alternatives available for waterproofing and the need to consider the underlying geology and hydrology, each basement is designed on a site-specific basis with appropriate risk assessment and options appraisal, by an appropriately experienced and qualified design team including input from waterproofing specialists where needed.

Forms of construction with the potential for large numbers of joints (e.g. piled walls and insulated concrete form systems) can be more prone to leakage unless great care is taken during construction and, ideally, are to be avoided on high gas risk sites if possible. Basements using Type C protection (i.e. drained cavities) might pose an unacceptably high risk on sites affected by ground gas. Infiltrating water might contain dissolved gas and/or contain organic compounds that can degrade to form methane and/or carbon dioxide.

In general terms, a basement constructed of dense cast in-situ concrete appropriately designed to BS EN 1992 to provide integral waterproof protection normally represents the most impermeable structural forms. Combining this with a waterproof membrane to create a fully tanked basement provides the best basement solution for preventing the ingress of ground gases.

The ability of concrete to provide resistance to the passage of moisture and ground gases is strongly reliant upon the design and construction achieving defect-free high quality dense concrete. Furthermore, the control of cracking achieves low permeability. Adequately designed and detailed reinforcement can significantly reduce susceptibility to cracking.

Appropriate treatment of joints within the concrete basement structure prevents the ingress of moisture and ground gases. Joints may be formed as construction or day works joints, expansion joints or to cater for services or other penetrations. Waterstops or waterbars are needed at joints to provide continuity of any integral waterproofing and they may be passive systems (e.g. extruded rubber or PVC profiles), active systems (e.g. hydrophilic strips or crystallisation slurries) or post injection systems.

Service entry locations and physical penetrations through basement structures pose a potentially high risk to the continuity and integrity of any waterproofing and/or gas protection system. These are to be fully considered during the building design and not left to chance during construction. Appropriate detailing around service penetrations and appropriate ducts, puddle flanges or proprietary systems that allow adequate sealing is important.

Where ground gas is of concern, gas resistant membranes are normally required because protection through structural integrity alone cannot be guaranteed. If tanking or a barrier system is not provided in addition to integral protection then a specific risk assessment is required to validate the gas resistance offered by the structural design.

To maximize resistance to water and gas ingress, and achieve good quality dense concrete with low permeability, the design and construction of a basement structure needs to:

- ensure the design limits the potential crack widths that might occur in the concrete with the provision of adequate reinforcement and appropriate detailing;
- adopt appropriate pour sizes to mitigate the potential for cracking;
- have appropriate quality control and workmanship on-site to ensure that the concrete is adequately compacted during placement and properly cured post placement;
- use appropriate waterstops at construction and/or movement joints to maintain the continuity of the system (any proprietary products need to be used strictly in accordance with manufacturer's recommendations); and
- ensure that service entries and other penetrations are considered during the design and appropriately sealed.
- When void formers are used beneath the lowest basement slab to accommodate clay heave, this creates a void in which ground gas can accumulate.

A.5 Influences of cracks and other pathways in concrete floor slabs and basement walls

The ability of concrete to provide resistance to the passage of both moisture and ground gases is strongly reliant upon the design and construction achieving defect free high quality dense concrete. Cast in-situ concrete can be affected by:

- plastic cracking after the initial placement of the concrete due to excessive bleeding/evaporation rates;
- micro cracking occurring during the hydration process due to inadequate curing;
- shrinkage cracking due to thermal effects, segregation or honeycombing due to inadequate compaction; and
- structural cracking acquired during the application of service loads (e.g. tension cracks).

For concrete substructures, any cracking that develops increases the permeability. Non-structural (limited depth) cracks have less influence on the gas permeability of the concrete slab or basement wall than structural cracks going through the concrete. Adequately designed and detailed reinforcement helps reduce susceptibility to cracking.

Joints in the construction, gaps between the floor and the walls and the number of openings within the floor (e.g. service penetrations) might strongly influence the resistance to gas ingress.

Additionally, the thickness and areal extent of the slab (e.g. large industrial floor slabs) influences the rate of diffusion through the concrete, if a concentration difference exists between opposite sides of the concrete element. This is mainly a design consideration where substantial building footprints are intended.

An important consideration is also the detail at junctions between the floor and wall or isolation joints. In the case of ground bearing slabs the edge of the floor slab is not built in to the surrounding walls. This can allow gaps to form along the slab perimeter due to settlement, movement and shrinkage. These gaps create preferential pathways for gas ingress and can potentially cause damage to membranes.

Raft foundations avoid such joints as the slab and stiffening ground beams are normally formed from cast in-situ concrete in one operation to form a monolithic substructure.

A.6 Overall risk rating for ground gas ingress for different types of building floor slabs and for basements

Table A.2 provides a risk rating summary for ground gas ingress.

Table A.2 **Risk rating summary**

Substructure/ground floor type	**Risk ratings**				
	Gaps between member elements	**Wall to floor crack**	**Structural cracking**	**Micro cracking**	**Overall risk rating**
Precast suspended segmental subfloors without and/or with bonded reinforced structural concrete topping (e.g. beam and block)	Moderate to high	Low	Low	Low to moderate	Very high
Cast in-situ ground bearing floor slab with mesh reinforcement for crack control constructed off a sound sub base (e.g. traditional ground bearing floor slab)	Low	High	Moderate	Moderate to high	High
Cast in situ monolithic reinforced concrete ground bearing raft or suspended/semi-suspended cast in situ reinforced concrete slab with minimal penetrations	Low	Low	Low	Low to moderate	Medium
Cast in situ reinforced concrete basement constructed to provide Grade 2 or Grad 3 (BS 8102:2009) waterproofing	Low	Low	Low	Low	Low

Annex B (normative) Applicability and design of ventilation protection measures

B.1 General

*COMMENTARY ON **B.1***

Ventilation protection measures typically take the form of a sub-floor gas dispersal layer formed directly beneath the ground floor slab, or beneath a gas membrane if one is placed beneath the floor slab.

Ventilation protection measures should only be used with an overlying barrier formed by an appropriately detailed and constructed slab and/or a gas membrane.

*NOTE Passive dispersal layers cannot usually be designed to work effectively beneath basement slabs. However, internal ventilation can be considered as part of the gas protection system for such areas of the building (see **B.5** for further information).*

This Annex covers the following topics:

a) objective of ventilation protective measure;

b) typical systems of ventilation protective measures;

c) active systems;

d) suitability and design considerations for passive ventilation systems;

e) general considerations for all passive ventilation systems;

f) clear void dispersal layer;

g) polystyrene void formers;

h) gravel layers;

i) gravel layers with drains;

j) design considerations for active ventilation systems; and

k) basements.

B.2 Objective of ventilation protective measures

*COMMENTARY ON **B.2***

The objective of having a gas dispersal layer is to reduce the concentrations of hazardous gases directly beneath the floor slab to acceptable levels.

Acceptable concentrations within the gas dispersal layer vary according to the hazardous gas(es) present; however, the diluted concentration of each gas should be sufficiently low such that if the overlying barrier protection fails, the ingressing gas does not present a significant health hazard to the occupants.

B.3 Typical systems of ventilation protective measures

*COMMENTARY ON **B.3***

There are two types of ventilation protection systems:

a) passive systems; and

b) active systems.

B.3.1 Passive systems

*COMMENTARY ON **B.3***

Passive systems do not include pumps or require an electrical power supply. They comprise a sub-floor gas dispersal layer where ground gases entering the base of the layer are mixed with external air which is being drawn through the layer by natural air pressure differences between opposite sides of the building, or by air pressure differences which arise from wind flow across cowls at roof level.

The principles and general arrangement of passive gas protection measures that should be followed are illustrated in Figure B.1, Figure B.2 and Figure B.3.

NOTE Dispersal layers in passive systems have been formed of all of the following media in the UK, but their performance and applicability to different gas regimes varies considerably (for further details on suitability see ***B.4****):*

a) void space;

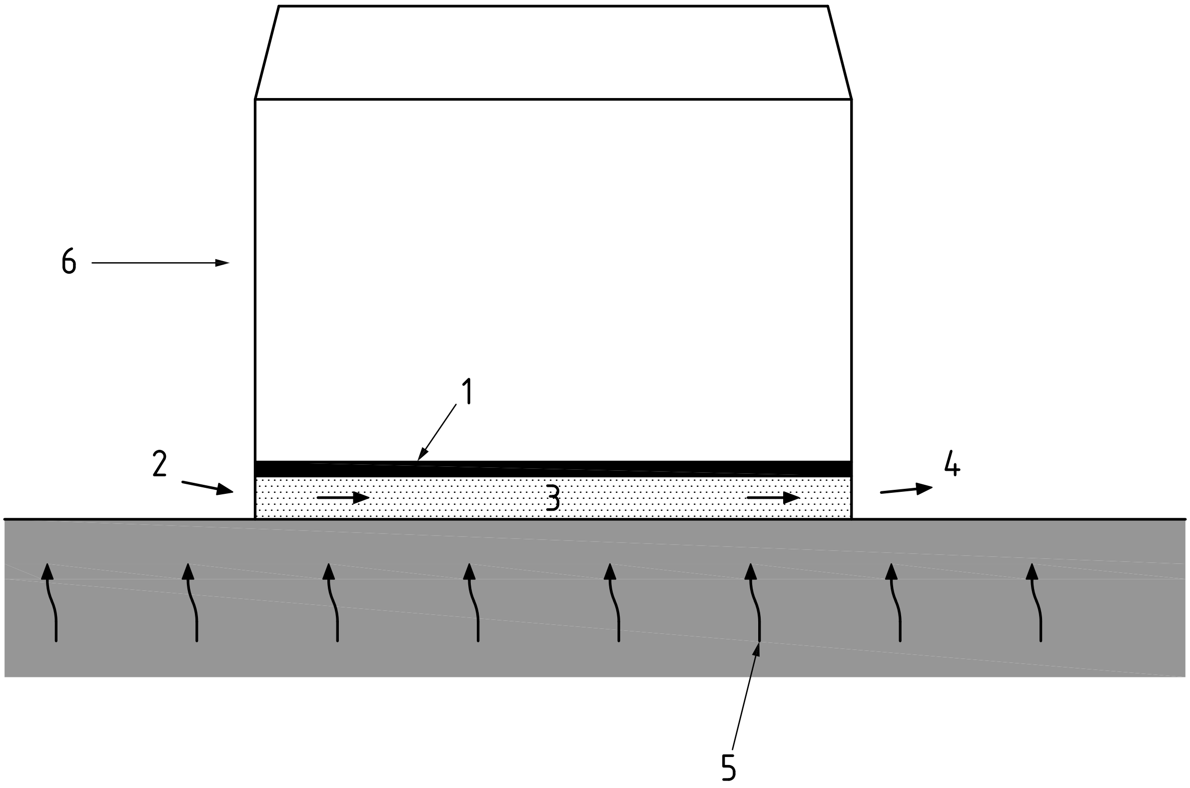
b) polystyrene void formers;

c) geocomposite void formers;

d) low fines gravel layer; and

e) low fines gravel layer with gas drains.

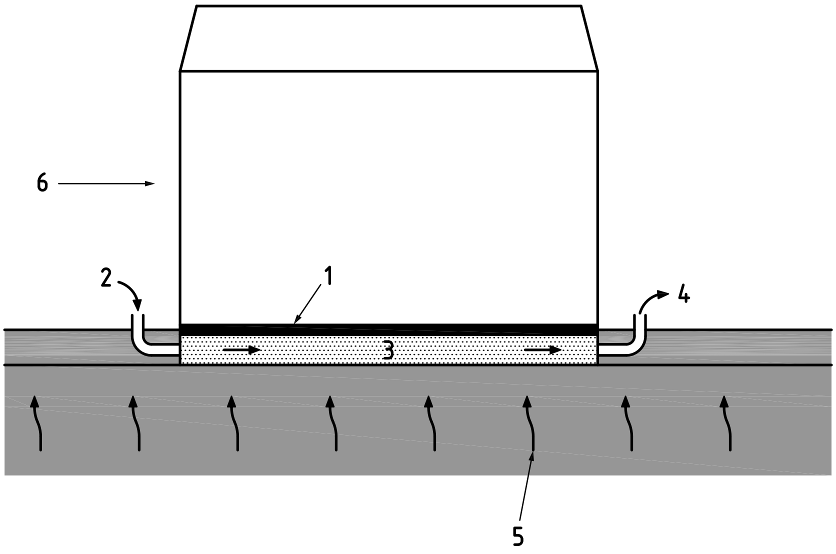
Figure B.1 **Typical passive ventilation arrangement with floor slab above ground level**



Key

1	Floor construction including membrane
2	Fresh air in
3	Gas dispersal layer
4	Fresh air and ground gas out
5	Ground gases
6	Wind direction

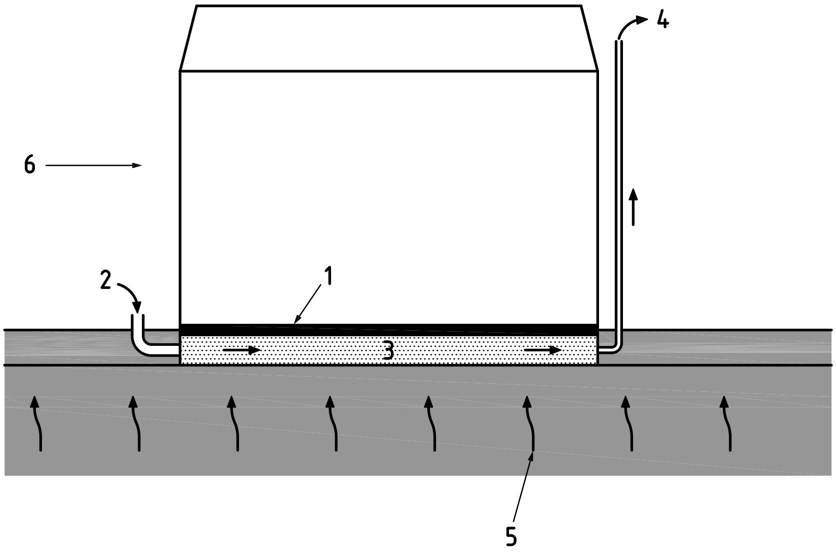
Figure B.2 **Typical passive ventilation arrangement with floor slab below ground level and low level vents**



Key

1 Floor construction including membrane
2 Fresh air in
3 Gas dispersal layer
4 Fresh air and ground gas out
5 Ground gases
6 Wind direction

Figure B.3 **Typical passive ventilation arrangement with floor slab below ground level and high level vents**



Key

1 Floor construction including membrane
2 Fresh air in
3 Gas dispersal layer
4 Fresh air and ground gas out
5 Ground gases
6 Wind direction

B.3.2 Active systems

B.3.2.1 General

Active systems involve air pumps and need an electrical power supply; these should not be specified for private residential buildings but can be used for managed buildings, although they are less preferable than passive systems and are also less sustainable.

NOTE There are two types of active systems in use:

a) positive pressurization clean air blanket; and

b) active suction systems.

B.3.2.2 Positive pressurization

COMMENTARY ON ***B.3.2.2***

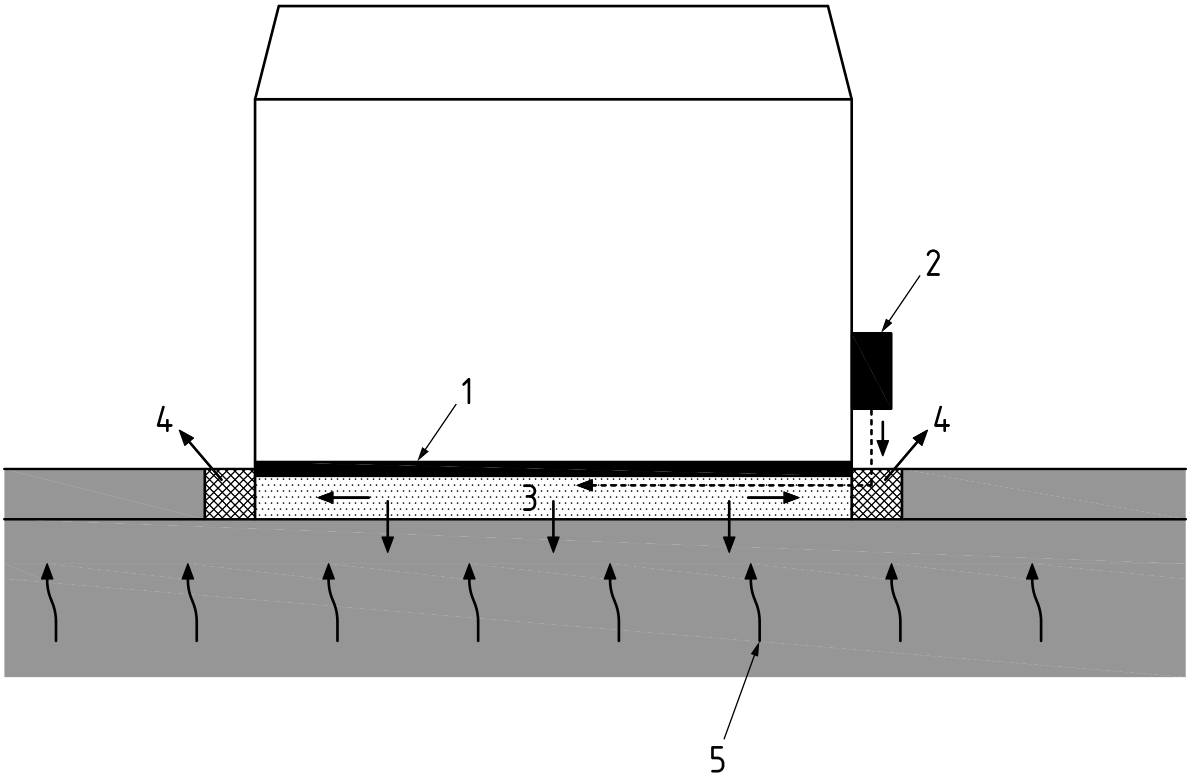
The positive pressurization air blanket system, which is the more common active system, involves pumping a continuous supply of external air to supply point(s) beneath the centre of the floor slab. These point(s) are within a thin permeable dispersal layer which extends beneath the whole floor slab to the edge of the building and beyond. The objective is for the injected external air to flow through the dispersal layer to vent points just beyond the perimeter of the building and to form a barrier layer of air directly beneath the floor slab.

Air blanket systems should be designed to provide sufficiently elevated air pressure and an even flow rate within the dispersal layer across the whole building footprint; the principles and general arrangement of the positive pressurization air blanket system are illustrated in Figure B.4.

B.3.2.3 Active suction systems

These active suction systems (see Figure B.5) use air pump(s) to generate flow through a sub-floor dispersal layer by applying mechanical suction. The pumps should be designed to either run continuously or to be activated by gas concentration monitoring switches (when gas concentrations build up above set threshold levels within the gas dispersal layer). In this latter case, the system is passive when the pump(s) are off and active when the pump(s) are operating.

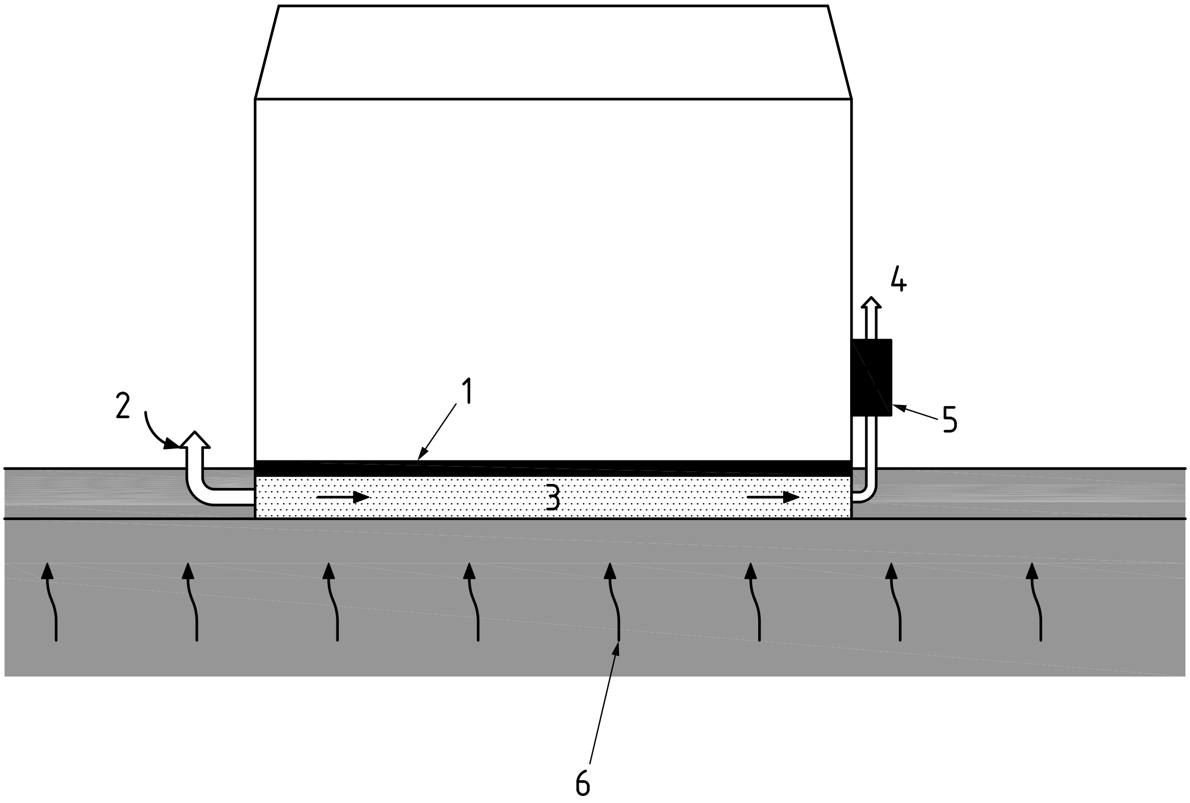
Figure B.4 **Positive pressurization air blanket system**



Key

1	Floor construction including membrane
2	Air pump (fresh air in)
3	Clean air blanket
4	Fresh air and ground gas out
5	Ground gases

Figure B.5 **Typical active suction system with floor slab below ground level**



Key

1	Floor construction including membrane
2	Fresh air in
3	Gas dispersal/abstraction layer
4	Fresh air and ground gas out (at high or intermediate level)
5	Air pump (suction)
6	Ground gases

B.4 Suitability and design considerations for passive ventilation systems

*COMMENTARY ON **B.4***

Research work was undertaken to evaluate the performance of different dispersal media and systems by the Department of the Environment, Transport and the Regions (DETR) Partners in Technology (PiT) and the results are reported in Passive Venting of Soil Gases Beneath Buildings, Guide for Design [12]. The research involved computational fluid dynamic (CFD) modelling of two widths of idealized dispersal layers (5 m and 30 m), to represent small and large buildings. A total of six models were used (Models 1 to Model 6). Six rates of gas emission from the ground into the dispersal layer were considered. These were defined as gas regimes A to F and were each a unique combination of a hazardous gas concentration and gas standpipe emission flow rate, as set out in Table B.1. A comparison of these gas regimes with CIRIA 665 [6] CSs (set out in Table 2) is given in Table B.2.

Table B.1 **Gas regimes considered in the DETR/PiT *Guide for Design* [12]**

Gas regime	Hazardous gas concentration % v/v	Gas standpipe emission velocity ms	Equivalent total gas standpipe volume emission flow L/h [A]
A	1	0.005	35
B	5	0.005	35
C	5	0.01	71
D	20	0.005	35
E	20	0.01	71
F	20	0.05	177

[A] Assumes a 50 mm diameter gas standpipe.

Table B.2 **Gas regimes considered in the PiT *Guide for Design* [12]**

CIRIA C665 [6]		**PiT [12]**		
CS	GSV L/h	Gas regime	GSV L/h	Equivalent CS
1	<0.07	A	0.35	2
2	0.07 to <0.7	B	1.77	3
3	0.7 to <3.5	C	3.53	4 (low)
4	3.5 to <15	D	7.07	4
5	15 to <70	E	14.14	4 (high)
6	>70	F	70.69	6

For each gas regime, a range of different pressure differences were applied to the opposite sides of the idealized dispersal layers, to represent a range of different wind-induced pressures that would (principally) arise from wind speeds of 3 m/s, 1 m/s and 0.3 m/s. The steady state hazardous gas concentration in the dispersal layer was then computed by CFD simulations and the results judged in a scale from very good to unsuitable according to the steady state concentration achieved.

Underfloor passive ventilation systems should be designed to provide sufficient air flow to dilute ground gases to acceptable concentrations within the dispersal layer beneath the floor slab for most or all of the time.

NOTE 1 Since passive systems rely on wind to induce pressure driven flow, when there is negligible wind, there is no flow-through of clean external air and ground gas concentrations in the dispersal layer builds up. However, still wind conditions principally occur when there is high atmospheric pressure, whereas ground gas emissions into the dispersal layer are greatest when there is falling and low atmospheric pressures, which are always characterized by windy conditions or when the surface of external areas to the building are temporarily frozen or saturated.

NOTE 2 Whereas simple calculations for the side ventilation of a clear air void space dispersal layer can be undertaken (see BS 5925:1991), this approach cannot easily be applied to other dispersal media.

NOTE 3 The relationship between the hazardous gas flow rate from a standpipe (measured as flow or as velocity from a 50 mm diameter standpipe) and the rate of gas emission from the ground beneath the idealized dispersal layer (X in L/h.m^2) was assumed using the following formula (see Methane and the development of derelict land [14]):

$$X = \frac{GSV}{10} \tag{B.1}$$

This assumes that the gas emission from a borehole standpipe is representative of 10 m^2 of ground, which is considered an upper bound of the surface emission rate (see Gas protection – a common sense approach [15]).

The types of dispersal media considered and the variables in the computations are listed in Table B.3 and the proposed performance assessment for methane and carbon dioxide are reproduced in Figure B.6 and Figure B.7, respectively; these performance criteria should be used for design of sub-floor ventilation measures.

Table B.3 – Variables in the DETR/PiT *Guide for Design* [12]

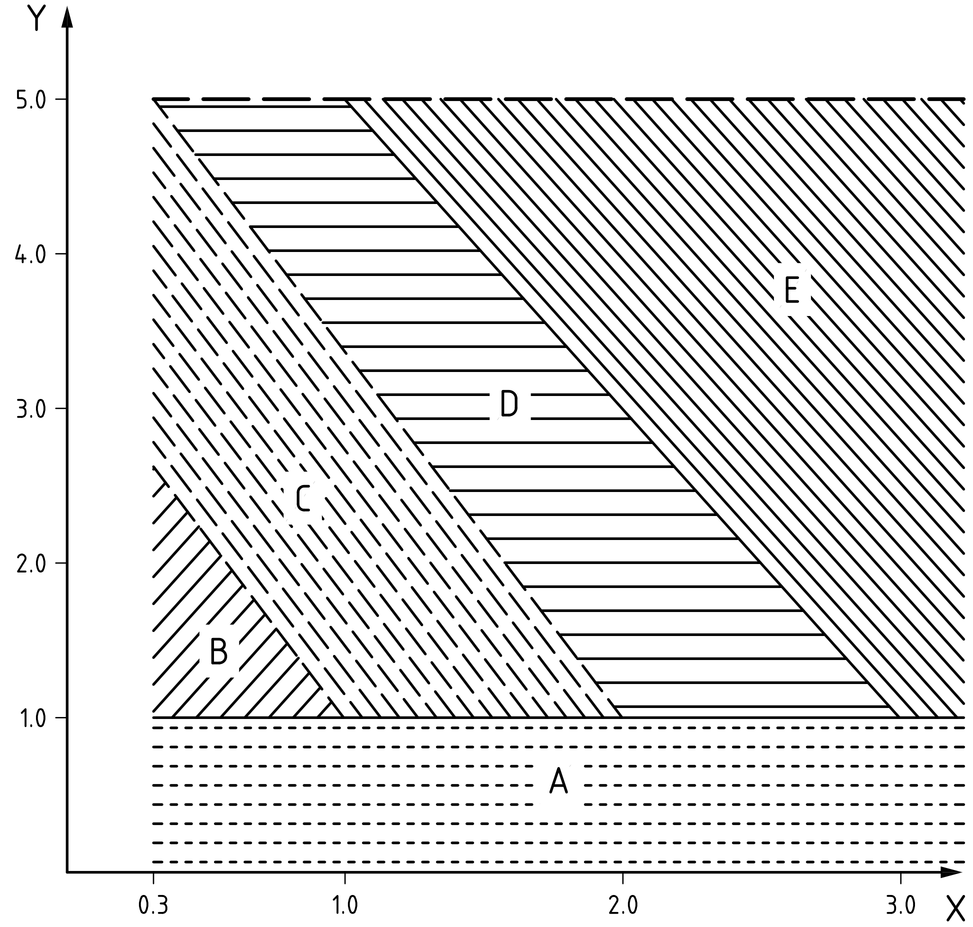
Dispersal layer media	**Primary variables** mm	**Side ventilation variables** mm^2/m	**Other variables** mm
Clear void	Void depths: 200 and 400	2 210 2 652 4 420	—
Polystyrene shuttering	Equivalent clear void depth [A)]: 22; 33; 60; and 100	2 210 2 652 4 420	—
Geocomposite drainage blanket	40 cuspated (36 equivalent clear void depth) [B)]	2 210 2 652 4 420	—
No fines gravel blanket	Thicknesses: 200 and 400	2 210 2 652	20 single size grading [C)]
No fines gravel blanket with perforated pipe gas drains	Drains at 2 000 and 3 000 centres	524 to 3 140	200 blanket (5 000 × 5 000) 400 blanket (30 000 wide)

[A)] The equivalent clear void is the volume of the void around the legs of the void former, expressed as a layer of clear space. The overall heights of the void formers modelled were: 80 mm (square leg); 100 mm (square leg); 150 mm (round leg) and 200 mm (round leg). The 150 mm and 200 mm high void formers were specifically designed as a gas dispersal layer void former.

[B)] The equivalent clear void depth is the volume of the void around the cusps of the void former, expressed as a layer of clear space.

[C)] Modelling was also carried out on MOT Type 1 (well graded) gravel. However, this was shown to be a completely unsuitable gravel for use in a gas dispersal layer.

Figure B.6 **Performance criteria for methane**

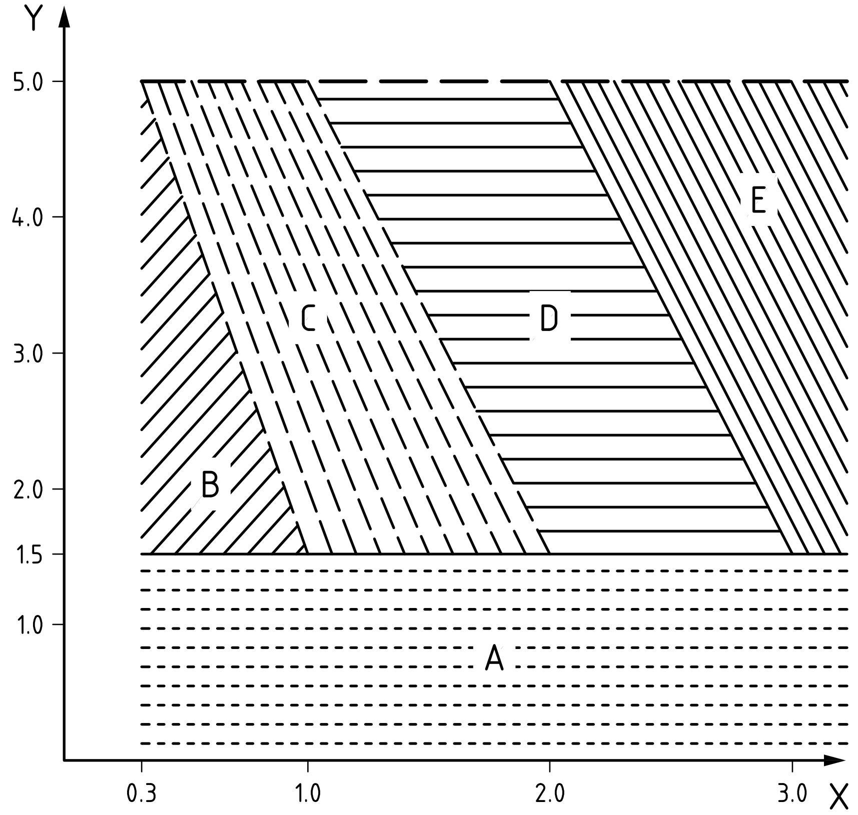


Key

A	Very good	X	Wind speed (m/s)
B	Good	Y	Maximum hazardous gas concentration in ventilation layer (% v/v)
C	Fair		
D	Poor		
E	Unsuitable		

NOTE The information in this figure is based on Passive Venting of Soil Gases Beneath Buildings. Guide for Design [12].

Figure B.7 **Performance criteria for carbon dioxide**



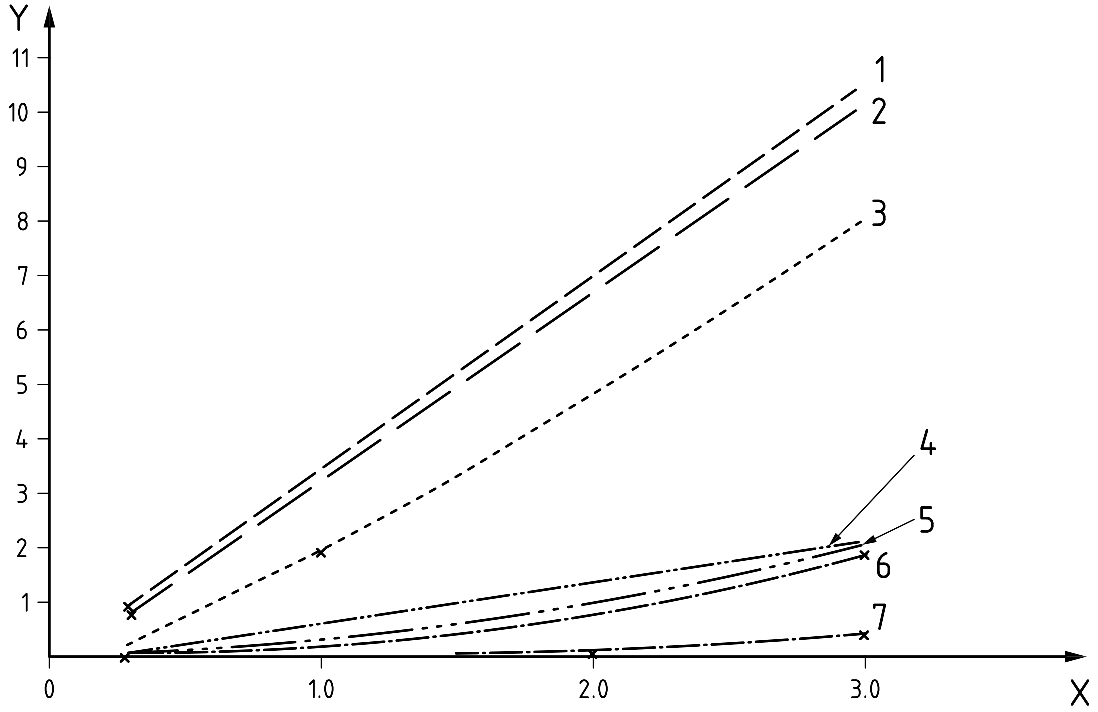
Key

A	Very good	X	Wind speed (m/s)
B	Good	Y	Maximum hazardous gas concentration in ventilation layer (% v/v)
C	Fair		
D	Poor		
E	Unsuitable		

NOTE The information in this Figure is based on Passive Venting of Soil Gases Beneath Buildings. Guide for Design [12].

NOTE 4 The DETR/PiT research - Passive Venting of Soil Gases Beneath Buildings. Guide for Design. [12] - and subsequent additional CFD modelling results and interpretation published by two of the DETR/PiT research authors provides the basis of the understanding of the effectiveness of alternative dispersal media and how passive systems can be designed. An illustration of the relative performance of different media for a 30 m wide idealized dispersal layer with no internal discontinuities and similar side ventilation provision is provided in Figure B.8 and for a 5 m by 5 m wide idealized dispersal layer in Figure B.9.

Figure B.8 **CFD computed volume flow through rates vs wind speed for various media for a 30 m wide foundation [12]**



Key

1 Open void 200 mm deep (Model 2)

2 Polystyrene shutter, 100 mm equivalent clear space (Model 2)

3 Polystyrene shutter, 22 mm equivalent clear space (Model 2)

4 20 mm (no fines) gravel blanket (400 mm thick with interleaved pipes at 3 m alternate centres (Model 5)

5 20 mm (no fines) gravel blanket (400 mm thick with pipes (not interleaved) at 2 m centres (Model 4)

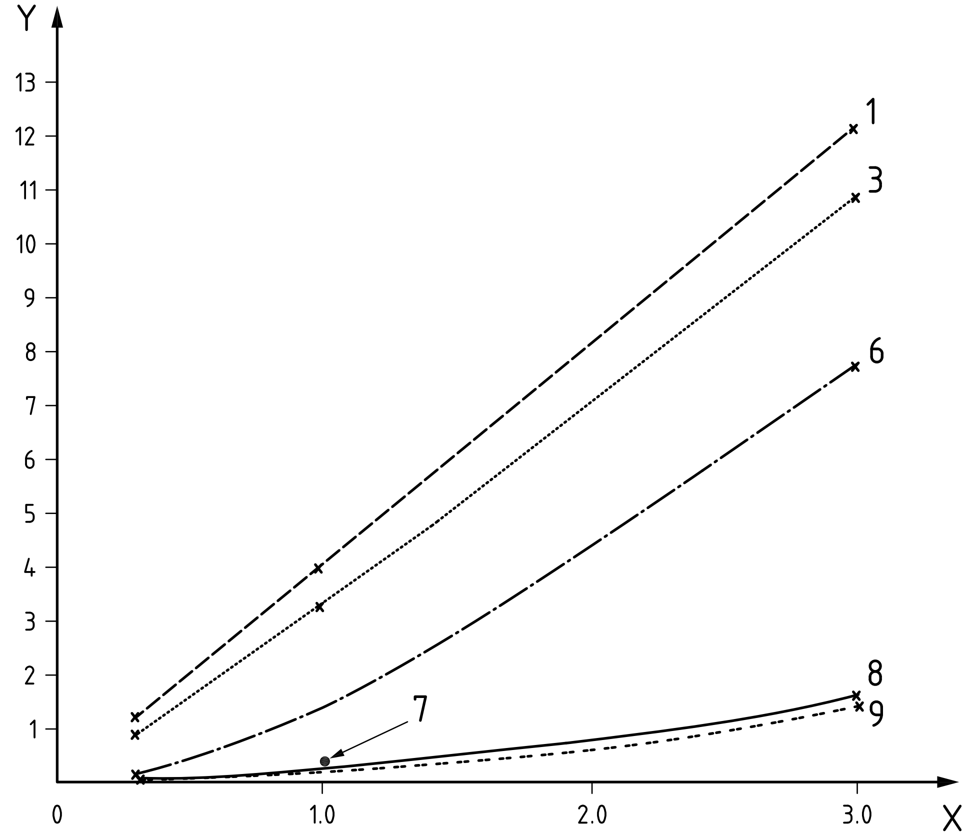
6 40 mm thick cuspated geocomposite void former blanket (Model 2)

7 20 mm (no fines) gravel blanket, 400 mm thick (Model 2)

X Wind speed (m/s)

Y Volume flow rate of air through dispersal layer (m^3/m width/h)

Figure B.9 **CFD computed volume flow through rates vs wind speed for various media for a 5 m by 5 m wide foundation [12]**



Key

1	Open void 200 mm deep (Model 1)
3	Polystyrene shutter, 22 mm equivalent clear space (Model 1)
6	40 mm thick cuspated geocomposite void former blanket (Model 1)
7	20 mm (no fines) gravel blanket. 400 mm thick (Model 1)
8	20 mm (no fines) gravel blanket. 200 mm thick with pipes (not interleaved) at 2 m centres (Model 3)
9	20 mm (no fines) gravel blanket, 200 mm thick (Model 3)
X	Wind speed (m/s)
Y	Volume flow rate of air through dispersal layer (m^3/m width/h)

NOTE In the Figure and the Key, 2, 4 and 5 are not used.

On the basis of the CFD modelling, the scale of potential dispersal effectiveness of different passive gas dispersal media for different sizes of foundation is set out in Table B.4; the actual dispersal effectiveness depends on adequate design, which should take into account the guidance given in **B.5** to **B.10** and should include input from an appropriately qualified and experienced specialist.

NOTE 5 The relative dispersal effectiveness from Table B.4 reflects the results of modelling on products available in the mid to late 1990s. Other cuspated geocomposites have been developed since that time which are likely to differ in performance to those modelled.

NOTE 6 The CFD modelling in the mid to late 1990s assumed low level air brick side vents. The provision of high level vents or fans would improve performance.

Table B.4 **Relative dispersal effectiveness of different gas dispersal layer media**

Dispersal layer media	Large foundation dispersal effectiveness	Small foundation dispersal effectiveness
Clear void	Very effective	Very effective
Polystyrene shuttering [A)]	Effective	Very effective
Cuspated geocomposite drainage blanket (min. 25 mm thickness)	Poor effectiveness	Effective
Single size (no fines) granular aggregate blanket with perforated pipe gas drains	Poor effectiveness	Effective
Single size (no fines) granular aggregate blanket	Very poor effectiveness	Poor effectiveness
Well graded granular aggregate blanket (e.g. MOT Type 1 or Type 2 aggregate)	Ineffective	Ineffective

[A)] There are a range of types and sizes of polystyrene shuttering which have differing dispersal effectiveness (**B.7**).

B.5 General considerations for all passive ventilation systems

The dispersal layer across the footprint of the building should be uniform. If there are downstanding beams or changes in level of the layer, this significantly reduces the efficiency of the media to disperse ground gas by pressure driven flow; obstructions to the layer should have cross vents at least double the area of the side ventilation.

Vents at the edges of the dispersal layer should be designed to cause minimal pressure drop and should be a piped system if the dispersal layer is below external ground level.

NOTE 1 Termination into gravel trenches around the perimeter of the building significantly increases the resistance to passive flow in the dispersal layer, and thereby reduce its effectiveness. If gravel trenches are used as the ventilation terminal on one or more sides of the dispersal layer, the maximum points score is 0.5 points (which is pressure relief only).

NOTE 2 Vents which are terminated several metres above ground level on one side of the building (for example at building roof level) can usually provide a greater differential pressure across the dispersal layer than low level vents on both sides of the building. The greater differential pressure causes a greater dilution of ground gases in the dispersal layer. The suction effects of rotating cowls, or air flow across an open pipe, and thermal stack effects are the reasons for increased pressure differential.

Regular inspections (and maintenance as necessary) should be made to check that side vents are not blocked and elevated cowls are functioning correctly.

*NOTE 3 Monitoring systems with alarms, such as those used for active venting systems (see **B.11**), are sometimes installed to provide an indication of whether the venting system is working as planned. If the alarm sounds too frequently consideration can be given as to why this is the case and whether the effectiveness of the system can be improved, e.g. by installing spinning cowls on the exit vents or installing mechanically operated fans.*

B.6 Clear void dispersal layer

NOTE An open void space provides the most efficient gas dispersal layer. It is suitable for gas regimes up to and including CS4.

The volume flow-through rate is governed by the size and number of side vents; for small to medium width buildings (up to 15 m wide), the minimum area of side ventilation should be 1 500 mm²/m run of wall on at least two opposite sides. For larger width buildings, the side ventilation provisions should be at least 2 000 mm²/m run of wall for gas regimes up to and including CS3 and 4 500 mm²/m run of wall for gas regime CS4. The minimum depth of the clear void space should be 100 mm. Where there are multiple internal obstructions to air flow (caused by beams), there should be four or five times the area of the side vents provided in the internal obstructions.

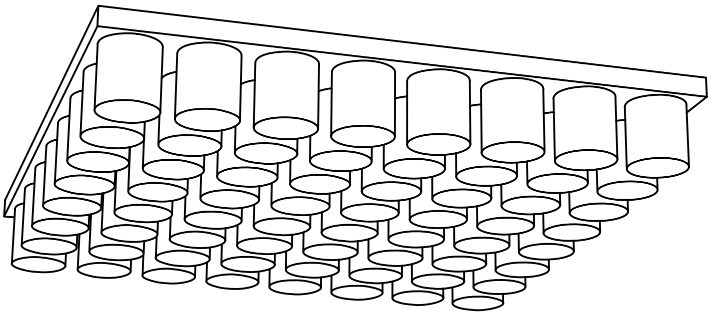
To assign a points score of 2.5 in Table 6, all of the recommendations in the paragraph above (in **B.6**) should be met. If the amount of side ventilation, or internal cross openings, are less than the above recommendations, then the score should be reduced to 2 or 1.5, depending on the additional obstruction to air flow in the layer.

B.7 Polystyrene void formers

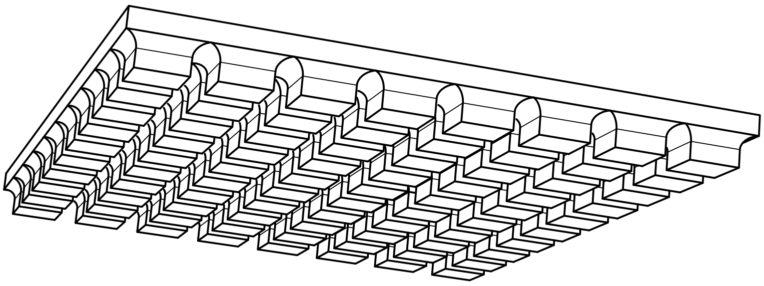
*COMMENTARY ON **B.7***

These void formers comprise a slab of polystyrene with stools (legs) that are used to temporarily support suspended cast-in-situ concrete floor slabs until the concrete hardens. The legs support the polystyrene slab off the ground and therefore create a void space beneath the slab. An illustration of this type of void former is given in Figure B.10. The product comes in a variety of heights and leg shapes, to suit different construction depths and loading, which provide different amounts of void space.

Figure B.10 **Polystyrene void formers**



a) Round leg, high voidage void former (manufactured for gas dispersal layer)



b) Square leg, lower voidage void former (manufactured primarily as temporary formwork)

A dispersal layer formed of the thicker high voidage polystyrene void former, which has a high void volume, compared to the volume of the legs, was shown by CFD modelling [12] to have a performance almost as good as a clear void (see Figures B.8 and B.9). Thinner products with less depth of leg and less void volume around the legs were shown to have less (but still very good) gas dispersal characteristics (see Figures B.8 and B.9).

A passive gas dispersal layer formed of polystyrene shuttering is suitable for gas regimes up to and including CS4. The volume flow-through rate is governed by the size and number of side vents.

The side ventilation provisions and openings through internal obstructions (e.g. ground beams) should be at least the same as those given in **B.6** for a clear void dispersal layer.

The maximum points score of 2.5 points (in Table 6) for polystyrene shuttering should only be assigned for the thicker products with an equivalent clear void depth of at least 60 mm, and comply with the minimum side ventilation and internal cross openings given in **B.6**. For the thinner polystyrene shuttering products, the maximum points score should be two points unless calculations demonstrate that "very good performance" as defined by Figure B.6 and Figure B.7 will be achieved.

In assigning an appropriate score for a particular project, consideration should be made by the designer of the gas protection measures to the as-built void space that exists during the life of the building. If the legs of the void former are seated on a soft layer (such as sand blinding) which fills up part of the void space, this should be taken into account and the points score reduced accordingly. Similarly, if clay heave is expected, which crushes the legs of the polystyrene void former over time, a reduced points score should be assigned.

NOTE If the void space becomes flooded with groundwater, it is no longer effective as a passive gas dispersal layer.

B.8 Geocomposite void formers

*COMMENTARY ON **B.8***

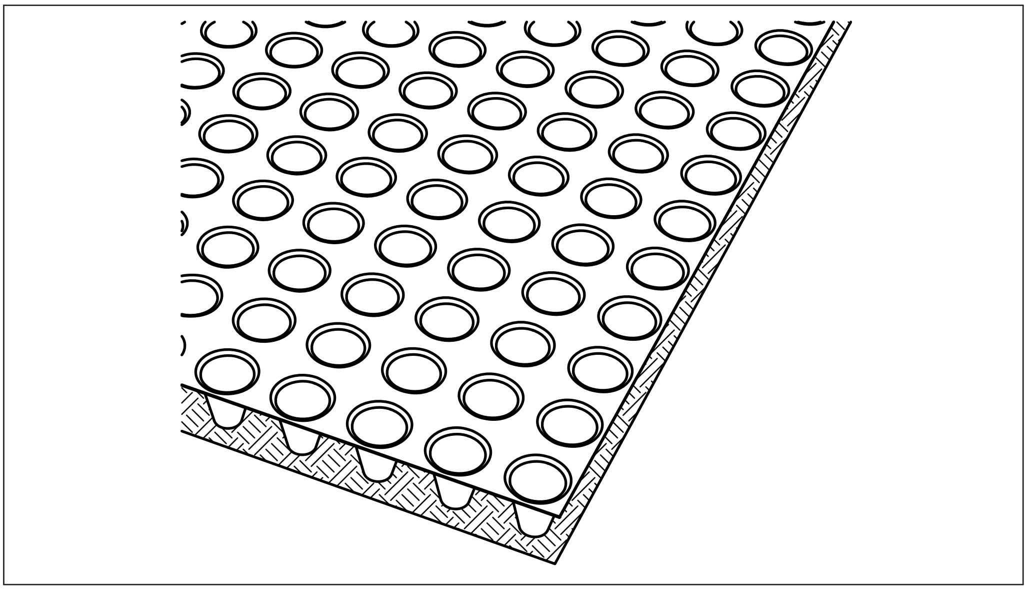
Many types and thicknesses of geocomposite strips have been used in passive and active sub-floor venting gas protection systems. These products were originally designed as groundwater drains, to be used vertically, however products are now manufactured specifically as gas dispersal media. The most common type of geocomposite used in gas protection systems comprises a cuspated high density polyethylene (HDPE) sheet (in strips) which has a geotextile fabric bonded to the end of the cuspates. An illustration of this type of product is given in Figure B.11. The typical installation detail is with the strips laid with the geotextile fabric at the bottom.

For a cuspated geocomposite void former dispersal layer, the DETR/PiT modelling indicated that the pressure head loss occurs across the width of the building (within the blanket), rather than at the side ventilation points. Therefore the dispersal effectiveness is a function of the width of the building and the thickness of the geocomposite blanket. (This is unlike clear void and polystyrene void former dispersal layers where the pressure head loss occurs at the side ventilation and through any internal constrictions.)

Geocomposite blankets are not suitable for CS4 (or higher) risk sites unless the width of the building is small (less than 5 000 mm to 8 000 mm); the minimum thickness of a cuspated geocomposite used as a blanket passive gas dispersal layer should be 25 mm.

For small to medium width buildings (up to 15 m wide), the minimum area of side ventilation should be 1 500 mm^2/m run of wall on at least two opposite sides. For larger width buildings, the side ventilation provisions should be at least 2 000 mm^2/m run of wall.

Figure B.11 **Geocomposite void former**



As a guide a points score of 1.5 in Table 6 can be applied for a 25 mm (or thicker) geocomposite blanket for buildings up to 15 000 mm wide; for larger width buildings (or thinner geocomposite blankets), the points score should be reduced to 1.0 or 0.5, depending on the width of the building. Geocomposite blankets thinner than 25 mm should not be specified for CS3 (or above).

If calculations demonstrate that "very good performance" as defined by Figures B.6 and B.7 will be achieved, a points score of 2.5 should be applied.

B.9 Gravel Layers

A granular aggregate gas dispersal layer should comprise either recycled materials (concrete and brick) or virgin washed or crushed aggregate. To be effective, the aggregate should not contain any significant amounts of finer material (clay, silt or sand) and the minimum particle size should be 20 mm.

NOTE 1 Well graded aggregates such as MOT Type 1 and Type 2 are unsuitable.

The layer should be a minimum of 300 mm in thickness and have a high porosity (greater than 40%); the layer does not normally have any mechanical compaction.

NOTE 2 The gas dispersal characteristics of granular aggregate layers are similar to geocomposite blankets, with the pressure head loss occurring within the aggregate layer and not at the side vent points. The gas dispersal characteristics of granular aggregate layers have been found to be directly proportional to their thickness and a methodology for their quantitative design is given in Gas protection measures for buildings, Methodology for the quantitative design of gas dispersal layers [16].

The minimum side ventilation provision should be the same as for geocomposite blankets.

For small floor slab footprints, it might be possible to design a gravel dispersal layer to achieve "good performance" or "very good performance" as defined by Figure B.6 and Figure B.7; if this can be justified by calculation, a points score of 1.5 or 2.5, respectively, can be applied, but if only a fair or poor performance is calculated, a reduced score of 1.0 or 0.5, respectively, should be applied.

For wide floor slab footprints,a gravel dispersal layer (provided it is comprised of a poorly graded, no fines gravel) usually only really provides a pressure relief function, in which case the score (Table 6) is 0.5 points; if the gravel contains a significant amount of fines (more than 10%) or is moderately to well graded (such as MOT Type 1 or Type 2 gradings), then the layer does not even provide pressure relief and zero points (see Table 6) should be assigned.

B.10 Gravel layers with drains

*COMMENTARY ON **B.10***

The gas dispersal characteristics of granular layers can be improved by introducing a network of drains to sub-divide the blanket into narrow sections and direct the mixture of fresh air and ground gas to the side vents. This can be particularly useful for large footprint buildings.

The drain network should be designed to cause external air to flow though all parts of blanket and not to short circuit between vent points on opposite sides of the building; this is achieved by having interleaved networks of pipes connected to opposite sides of the building, as illustrated in Figure B.12. The networks should be as symmetrical as possible.

Perforated plastic pipes and geocomposite strips are both used as gas drains; pipes should be at least 75 mm diameter and have a high degree of perforations (ideally at least 10%). Geocomposite strips should be 1 m wide and at least 12.5 mm thick. The drains should be at a spacing of not more than 3 m and be as close together as is practicable. The granular layer should be at least 200 mm thick.

NOTE Granular layers with drains are not sufficiently effective for use on CS4 (or higher) sites.

The gas dispersal performance of a granular blanket with gas drains is mainly determined by the combination of (a) the thickness and porosity of the granular layer and (b) the spacing between the drains, although the in-line resistance to flow of a geocomposite strip and the resistance to flow of the slots in pipes are also factors. The number and size of the side vents is less critical, however side vents should normally be provided at no more than 10 000 mm centres and have an area equivalent to 1 500 mm^2/m run of wall on at least two opposite sides.

B.11 Design considerations for active ventilation systems

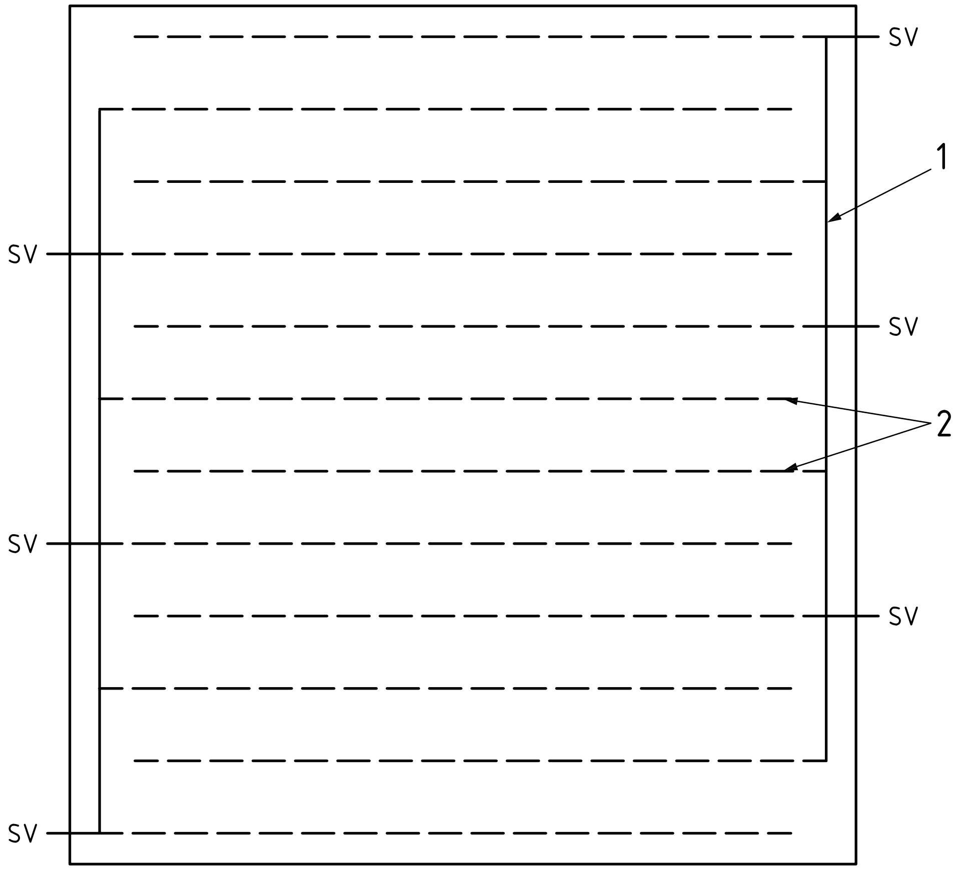
B.11.1 General

All systems with fans should be designed to vent passively whenever possible in the event that the fans stop working (e.g. due to power cuts).

A factor of safety should be applied to the required ventilation or fan capacity, depending on the sensitivity of the end use and the robustness of the conceptual site model and data for the site (including desk study, descriptions of the gas source as well as gas monitoring data).

NOTE A factor of safety between 1.5 and 3 is usually appropriate.

Figure B.12 **Idealized plan of granular gas dispersal layer with network of gas drains**



Key

1	Header pipe
2	Gas drains
SV	Side vent

B.11.2 Positive pressurization system

Positive pressurization air blanket systems should provide sufficient air flow beneath all parts of the floor slab to maintain the pressure of external air immediately below the slab at a level that is greater than the pressure driving the methane or carbon dioxide from the ground.

B.11.3 Active suction systems

For active suction ventilation of the gas dispersal layer, the volume of air flow required to dilute the maximum emission rate of the methane and carbon dioxide for the site's CS designation to acceptable levels should be estimated using the guidance in *CIRIA Report 149* [5]. Then a sufficient number of fans to meet the required capacity (allowing for factors such as safety, even air flow, and breakdowns) should be provided.

The fans might be designed to run continuously or be designed to automatically switch on when gas concentrations in the dispersal layer exceed a predetermined concentration; in the latter case there should be monitoring of gas concentration in the venting layer at several locations. This should be achieved using sensors placed in the venting layer or using a central monitor that draws samples to it through thin plastic tubes.

NOTE 1 Pellistor sensors in the void might become poisoned or otherwise incapacitated, and if not accessible they cannot be replaced or repaired.

If access to maintain the pellistors cannot be provided a system in which gas is drawn back through narrow pipes to a central monitoring unit should be used; the unit typically draws gas from each pipe in turn through a single sensor or group of sensors. The monitoring unit should preferably be fitted with a chart or digital recorder, which if not always on, is turned on when the fans activate.

Two trigger levels should be set for the monitoring system for each gas or condition of concern (e.g. different concentrations of methane).

NOTE 2 At the lower concentration, the extractor fans activate and an amber alarm is indicated on the control box and in a repeater panel located somewhere that is clearly visible to those using the building (e.g. the building's central services monitoring area). The higher concentration represents a "red alert" situation because it can only be reached if the fans have failed to actuate at the lower concentration (i.e. there is a fault in the system) or there is too much gas for the fans to effectively remove it. Such an alert might trigger evacuation of the building or at least formal consideration of whether this is necessary.

When an active system is installed, the building occupier should be provided with a manual describing how the system is intended to work, what response there should be to "amber" and "red" alerts, what maintenance is required of the fans and the monitoring system, and who to contact in the event that either appears to be malfunctioning.

B.12 Ventilated basements

*COMMENTARY ON **B.12***

The presence of a well-ventilated basement beneath the ground floor (and upper) parts of a building provides an air blanket, protecting the ground floor rooms and upper levels from ingressing ground gases.

The basement space itself should be adequately protected from the accumulation of harmful concentrations of ingressing ground gases, as described in Annex A.

NOTE 1 In this situation, a ventilation score (see Table 5) of 4 can be assigned for the ground floor above the car park. For the ground floor of the building over basement space used for other purposes, a ventilation score of 4 (Table 5) may also be assigned, provided an assessment of potential methane and carbon dioxide concentrations in the underlying basement rooms and spaces is undertaken and shows that there is adequate structural confinement and ventilation to ensure that harmful concentrations of these gases do not accumulate.

Ground gases might accumulate beneath and around basement structures and the measures to protect such parts of the building should include a combination of barrier(s) to prevent ingress of gases and adequate ventilation within the basement; barrier(s) are normally provided by the form of construction of the basement and the inclusion of waterproofing or a combined waterproofing and gas membrane, as necessary. There should be appropriate detailing of below ground service entries into basements.

NOTE 2 It is often not practical to provide effective passive ground gas dispersal layers around and beneath basements, although it is possible to provide preferential pathway media (such as a coarse granular curtain or a geocomposite drainage sheet around the sides of basement wall.

Annex C (informative) Gas resistant membrane selection

*COMMENTARY ON **Annex C***

Annex C provides guidance on the choice and use of membranes to resist the passage of methane and carbon dioxide.

*The properties of a gas resistant membrane which can be assigned a gas protection score according to the empirical methodology described in **7.2** are given in **7.2.4**.*

C.1 What to consider

Factors to be taken into account when specifying a membrane as part of a protection system to mitigate the risks from methane and carbon dioxide migration into buildings, include:

- the risk of gas migration into the building and how much reliance is to be placed on the membrane;
- the maximum permeation rate of methane and carbon dioxide through the membrane (permeation data);
- the membrane's expected exposure to concentrations of challenge chemicals that could adversely affect its durability and performance in the long term (the amount of resistance to the challenge chemicals);
- the membrane's subjection to tensile loads in the permanent condition (the tensile stength of material and welds allowing for loss of strength due to exposure to challenge chemicals);
- the required quality and robustness of the installation;
- the likelihood of damage to the membrane during and after construction – this helps define the required puncture resistance, impact resistance and tear strength;

  NOTE This is imporant because of the low permeation rates through the installed membrane.
- the need for welded seams (this determines the minimum thickness of the membrane);
- what verification and integrity testing of the materials, seams and seals, etc. are needed.

C.2 Available membranes

A wide variety of plastic geomembranes are available with very different properties and performance characteristics. The most common materials used in membranes for gas protection in the UK are:

- flexible polypropylene (FPP);
- high density polyethylene (HDPE);
- low density polyethylene (LDPE) or linear low density polyethylene (LLDPE);
- reinforced LDPE with an aluminium core;
- HDPE reinforced polypropylene (FPP) with aluminium core;
- HDPE/ethylenevinylalcohol (EVOH)/HDPE-sandwich; and
- spray applied asphalt-latex membranes (bitumen/polystyrene emulsions).

NOTE Membranes are available in a variety of thicknesses and types. Each material has different characteristics which affect installation procedures, durability, lifespan and resistance to damage and gas/vapour permeability [11]. Membranes can be reinforced to improve the durability of the material and prevent over elongation.

C.3 Advantages, disadvantages and points to consider with each type of membrane

FPP has good elongation, is flexible and does not suffer from environmental stress cracking but has relatively high gas permeability, is relatively expensive and has low adhesion with self-adhesive membranes or tapes. It requires specialist welding (not joining with tape). It is usually supplied on large rolls requiring plant for handling and is therefore generally suitable for large floor areas subject to the expected settlement.

HDPE has good puncture and chemical resistance, and is relatively inexpensive but prone to stress cracking. It is also relatively rigid, which makes it difficult to use in complex detailing or when notched by more than 10% of its overall thickness. It is produced in large rolls so is difficult to handle and has reduced adhesion with self-adhesive membranes and tapes. It requires specialist welding and is most suitable for large flat areas and where direct contact with heavily contaminated ground is expected.

LDPE and LLDPE are available in many different forms, both reinforced and un-reinforced, blown films, flat extruded and co-extruded. The material is flexible and is widely available. It is commonly used as a damp proof membrane (DPM) and is available in a number of gauges from 0.3 mm to 1.0 mm, although the most widely used is 0.5 mm. Unless the LDPE membrane is manufactured from virgin polymer and meets the recommendations set out in Table 7 (see **7.2.4**), it cannot be considered as a gas resistant membrane for the purposes of this British Standard.

NOTE 1 Low density polyethylene DPM has been used in the past as a gas membrane, but installation as a DPM is unlikely to provide robust gas protection. Furthermore, these materials are now usually manufactured from recycled polymer, and consequently both their physical properties and their permeation rates are variable, so these materials are not to be used as gas resistant membranes.

NOTE 2 A protection layer is generally required when placed directly under a reinforced concrete slab with any membranes, unless it can be robustly demonstrated this is not needed.

NOTE 3 Many of these membranes are manufactured with a centre fold for packaging which in many cases leads to large creases across the full width of the sheet. Rolls delivered to site with creasing are unacceptable as it is not possible to adequately seal joints where creasing is present.

Reinforced LDPE with an aluminium core offers high resistance to soil gases and is flexible with a high tear resistance. Protection of the aluminium core is critical if contact with alkaline surfaces is expected, and it has low ultraviolet (UV) light resistance (so needs to be covered). It also has low elongation due to reinforcement and a foil layer. It is normally produced from high quality virgin polymers as the film thickness and quality is critical for bonding. A minimum thickness of 0.4 mm (equivalent to 370 g/m^2 for polyethelene) is needed to provide sufficient protection and substrate for welding. It can be joined using welding techniques or tapes.

HDPE reinforced FPP with aluminium core offers high tear resistance and high resistance to soil gases but is relatively thin and difficult to join. FPP bonded to aluminium has poor adhesion unless an interlayer is used.

An HDPE /EVOH/HDPE sandwich offers very high resistance to hydrocarbon vapours and good resistance to other soil gases due to its construction. It also offers good elongation and puncture resistance, has high costs and complex installation due to HDPE surfaces. It offers advantages when high levels of resistance to vapours coupled with elongation are critical issues.

Spray on membranes can be applied to relatively uneven surfaces and areas with complicated detailing. They need a substrate geotextile on large flat areas. However, it is difficult to maintain constant thickness even if they are applied by experienced installation operatives.

NOTE 4 Geosynthetic clay liners (a thin layer of dry clay powder sandwiched between two geotextiles) are not suitable as barriers to gas migration into buildings. This is because the liner relies on the bentonite material becoming wet to form a barrier, which cannot be guaranteed. Even if it is pre-wetted during installation the clay can dry out in a building application where it is not exposed to infiltrating rainfall and might crack, thus allowing vapour to migrate through it. Test results for water vapour transmission on these types of barrier are not indicative of the likely rate of gas or vapour transmission.

Annex D (informative) Characterization without gas monitoring data

D.1 General

This Annex provides guidance for an empirical approach to characterizing sites without gas monitoring data where the source(s) of ground gas on the site is made ground with a low degradable organic content. It is not intended to be exhaustive and its proper application requires an understanding of the underlying scientific principles and technical issues.

NOTE 1 This approach is based on the method of characterizing a site without gas monitoring data described in RB17 [1].

NOTE 2 RB17 [1] also advises that it is possible to characterize sites where the only sources of methane and carbon dioxide are natural deposits, in the form of alluvium or carbonate strata (e.g. chalk) without gas monitoring data. In the case of alluvium, including deposits with buried peat layers, RB17 advises that it can be assumed that the site is CS2, due to the very low gas generation rates of such deposits. In the case of carbonate strata, RB17 [1] advises that the gas risk is negligible and no gas monitoring or protection measures are usually necessary. Before applying this empirical guidance, the conceptual site model is carefully assessed to check that there are not reservoirs of existing methane and/or carbon dioxide gases that could have preferential pathways to the underside of the new building development.

D.2 Principle

In this approach the representative gas regime (CS) is assigned based on:

- the conceptual site model, derived by updating the preliminary conceptual site model to take into account geological, hydrogeological and geotechnical data of an adequate ground investigation (BS 5930 and BS 10175) conducted to inform the design of the development;
- knowledge of the TOC content of potential ground gas generating made ground; and
- a detailed examination of the made ground soil material in accordance with Annex E.

D.3 Application

This approach may be adopted if:

- the preliminary conceptual site model has not identified any high gas generation sources; and
- the source is made ground that has less than 3 m average depth and 5 m maximum depth, and with TOC less than the limit for CS3 in Table D.1.

Table D.1 **Limiting values of thickness and organic content of made ground (after RB17 [1], Table 1)**

Thickness of made ground m	**Maximum total organic carbon content of made ground – TOC**		**Site characteristic situation (CS) to be assumed**
	Made ground in place for <20 years %	Made ground in place for >20 years %	
Maximum 5 m Average <3 m	≤1.0	≤1.0	CS1
Maximum 5 m Average <3 m	≤1.5	≤3	CS2
Maximum 5 m Average <3 m	≤4	≤6	CS3

NOTE Gas monitoring is required where TOC is greater than 4% (or 6% in old made ground). Gas monitoring results show whether the high TOC is available or not and if existing conditions are generating ground gas.

The bounding values for TOC, the thickness of made ground and the age of the made ground in Table D.1 are empirical and intended to be applied by taking into account all the available evidence, i.e. they are for guidance only.

This approach may:

- not be applied on its own to assess off-site sources or materials associated with waste disposal; and
- only be used to define sites with very low to moderate hazard potential (CS1 to CS3).

NOTE 1 This approach is limited to a maximum of CS3.

The TOC data is collected during an adequate site investigation for the development.

The TOC of soils is determined in accordance with BS EN 13137:2001.

NOTE 2 TOC is an analytical determinand defined by the analytical method used. Different analytical methods give different results. It is important therefore to only use the recommended method.

NOTE 3 Knowing the amount of degradable organic carbon that is present is important. However, there are no standardized methods by which this might be readily estimated. Hence, TOC is used as the defining parameter as this is a standard test for waste acceptance classification (WAC) testing carried out by commercial laboratories.

The applicable TOC value to be used in conjunction with Table D.1 is determined from the laboratory TOC results. These results are obtained on the <10 mm soil fraction of the made ground and adjusted, if necessary, to take into account the results of detailed examination of the materials present in the ground (see Annex E).

Information on TOC and on the physical make-up of the ground as determined by detailed examination of the materials present in the ground is collected with the same attention to the need for representative samples and adequate density of sampling as all other parameters that might be of concern on a potentially contaminated site [see BS 10175 and BS ISO 18400-104 1)].

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1) It is anticipated that BS ISO 18400-104 will be published in 2015.

Care is needed where made ground includes organic materials that are not readily degradable. For example, coal ash, clinker and coal can give high TOC results but the high TOC values do not necessarily represent the risk of gas emissions from such materials, which have a low degradable organic content (see Note 5). Such materials are generally not readily degradable so produce no more than low volumes per unit time of methane or carbon dioxide. In such cases, the assessor may estimate the degradable organic carbon content or the proportion of lignin, cellulose and hemi cellulose in the sample by testing (e.g. *Assessing MSW degradation by BMP and fibre analysis* [17]). Such an assessment is beyond the scope of this Annex.

NOTE 4 For example, coke breeze can contain up to 51% TOC but only 4% degradable organic carbon) (see Fundamentals, Instrumentation and Techniques of Sum Parameter Analysis [18]).

NOTE 5 The TOC value is based on detailed examination and laboratory testing of the made ground deposit so needs to take account of soil fractions that are fully representative of the deposit. For example, if made ground contains 30% organic material at 20% TOC and the remaining 70% of the soil fraction has a TOC of 0.5%, the overall TOC is 6.4%.

Discrete layers of highly degradable material are assessed separately from other made ground; for example, a layer of rotting vegetation or highly organic sediment at the base of in-filled ponds, as these can support higher rates of gas generation, and thus represent a higher risk situation.

If these are present, then this method is best supplemented by targeted boreholes and appropriate monitoring.

As with assessment using gas monitoring data, before assignment of a CS, careful consideration is given to possible changes in ground conditions that might arise from foreseeable natural events (e.g. changes in groundwater levels and sudden marked drops in atmospheric pressure), construction activities or on completion of the planned development (e.g. disturbance of the ground admitting water and air, inhibition of ground gas exchange with the atmosphere and creation of permanent pathways by which water and/or air could enter the ground).

All assumptions made leading to an assignment of a CS, and the reasoning behind them are carefully recorded and reported together with all relevant data and other information.

Annex E (informative) Sampling, examination and TOC testing of made ground for the assessment of the potential for gas generation

E.1 General

This Annex provides guidance on a method for estimating the amount of degradable organic material in a sample of made ground for the purpose of applying the approach of site characterization in Annex E.

NOTE 1 This Annex describes the detailed forensic examination referred to in Annex D.

NOTE 2 This Annex does not provide guidance on how to take samples, where to take them from or the number of samples required to provide an overall characterization of the ground in terms of the amount and type(s) of organic materials present.

E.2 Application

*COMMENTARY ON **E.2***

The most practical way to carry out the detailed forensic detailed examination in Annex E is to complete it on-site as samples are taken. This avoids having to transport and dispose of large volumes of sample material. Alternatively it may be completed at a geotechnical or chemical test laboratory.

Detailed examination of samples is carried out with regard as appropriate to:

- guidance on the pretreatment of samples in the field in BS ISO 18400-201 [2];
- guidance on handling, preservation and transport of samples to laboratories in BS ISO 18400-105 [3]; and
- guidance on pretreatment of samples in the laboratory in BS ISO 23909.

The results of the examination are used in conjunction with a careful observation and description of the ground from which the test sample has been taken.

E.3 Principle

A sample of made ground is taken and the main constituents divided into separate fractions. The fractions are weighed to determine the proportion of each in the sample.

E.4 Apparatus

Weighing scales are used that have a maximum capacity of at least 15 000 g with a readability of 0.02% of maximum capacity or 2 g, whichever is the lesser.

E.5 Sample

A sample of made ground with a weight of 10 000 g to 15 000 g is taken.

Larger samples (e.g. an excavator bucket-load) are reduced in size following the guidance in BS ISO 18400-201[2], as appropriate.

E.6 Procedure

The bulk sample is spread out on a suitable surface (e.g. plastic sheet).

The sample is divided into the following fractions following the procedures described in BS ISO 18400-201[2] or BS ISO 23909 as appropriate (e.g. sieving, hand-picking):

- fine soil materials including gravel less than 10 mm in size;
- coarse inert particles greater than 10 mm in size including clinker, gravel, concrete, brick, etc.;
- discrete fragments greater than 10 mm in size of, for example:
- woody material;
- vegetable matter;
- cloth, leather;
- metal, glass, ceramics and other inert materials;
- paper and card; and
- other degradable material.

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[2] It is anticipated that BS ISO 18400-201 will be published in 2015.

[3] It is anticipated that BS ISO 18400-105 will be published in 2015.

The less than 10 mm fine soil might contain discrete particles of organic material (e.g. wood). A decision might therefore need to be made as to whether or not to attempt to separate this by hand picking. If this is done, the mass of the material removed is recorded.

Each fraction is then weighed and the result recorded.

The total organic carbon content of the fine soil fraction (i.e. <10 mm) is determined in accordance with BS EN 13137.

E.7 Reporting

The test report includes the following information:

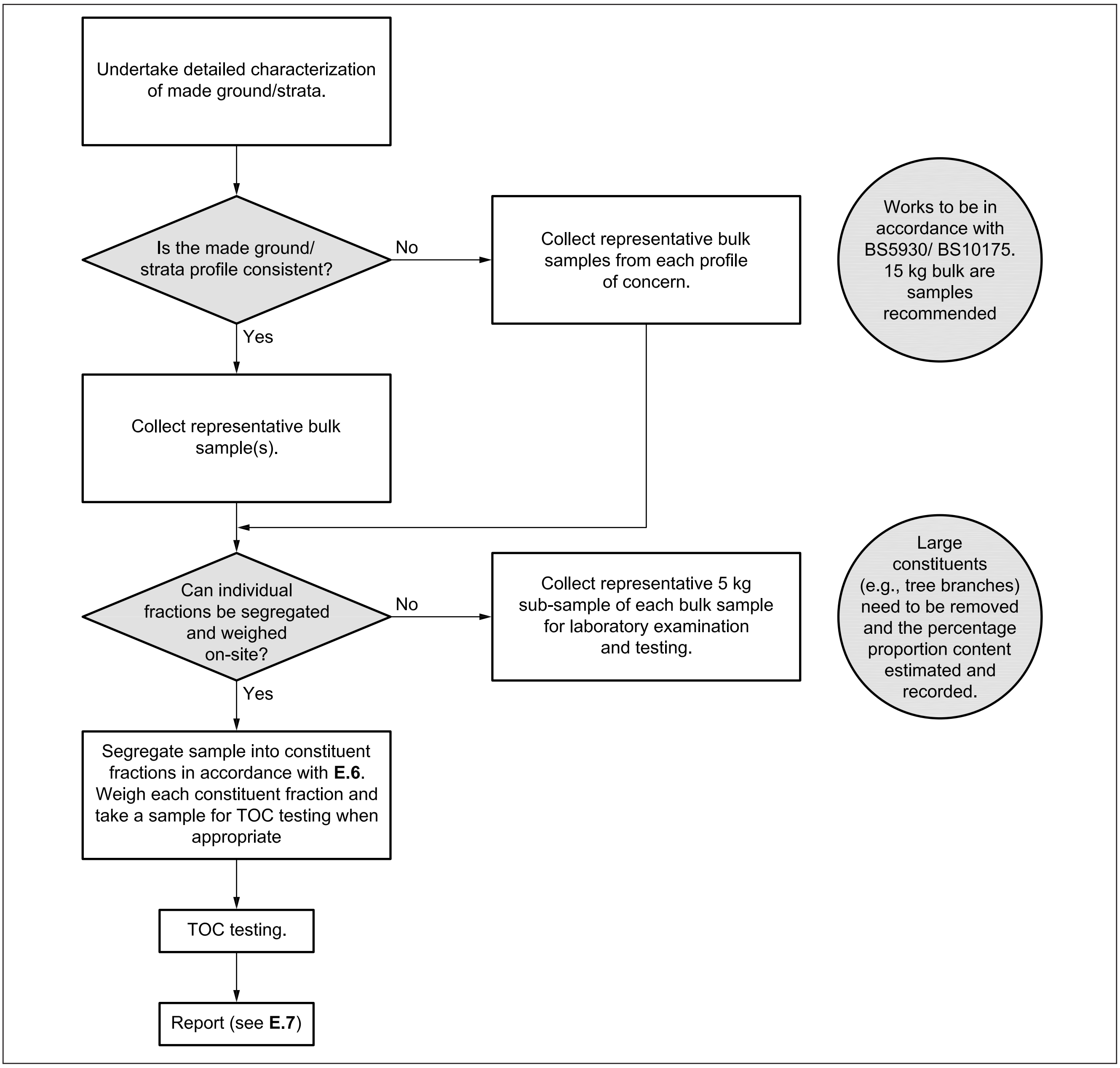
- site reference;
- sample reference;
- sample location and depth; and
- date of sampling.

It also includes the weight of each of the following fractions in the sample:

- fine soil including gravel less than 10 mm;
- organic fraction separated from the fine soil fraction if this has been done;
- coarse inert particles including gravel, concrete, brick, etc. greater than 10 mm;
- woody material, etc.;
- green vegetation, grass, food waste, etc.;
- cloth, leather;
- metal, glass, ceramics and other inert material;
- paper and card;
- other degradable material; and
- TOC content of fine soil fraction.

The approach used for detailed examination of made ground for the assessment of the potential for gas generation is given in Figure E.1.

Figure E.1 **Approach for detailed examination of made ground for the assessment of the potential for gas generation**



Annex F (informative) Worked examples

F.1 Scope of Annex F

This Annex provides examples of the interpretation of gas monitoring data and assignment of a CS by site characteristic GSV in accordance with the recommendations in **6.3** and application of the recommendations for selection of gas protection measures in Clause **7**. Two sites have been defined with different ground conditions and gas monitoring data; these are denoted Site A and Site B. Following the selection of the CS for each site, the gas protection measures for a range of different types of building are considered.

F.2 Site A

F.2.1 Site A ground conditions and available gas monitoring data

This is a typical estuarine site where there is a layer of made ground overlying alluvial deposits comprising clay and peat, overlying river gravel. A relatively high groundwater table is present within the peat, but this is not as responsive as the underlying gravel aquifer, where the groundwater response lags the tidal situation.

Based solely on knowledge of the potential gas sources (made ground and alluvium) an experienced assessor is likely to anticipate that the site will be a very low or low hazard potential site (CS1 or CS2).

A recent ground investigation, principally for geotechnical purposes, has already been carried out at the site which included the installation of five combined gas and groundwater monitoring borehole standpipes. Methane and carbon dioxide concentrations and standpipe emission flow rates were measured on three occasions in these five standpipes.

Table F.1 summarizes Site A ground conditions.

Table F.1 **Site A ground conditions**

Strata	Thickness m	Gas source	Gas investigation data
Made ground	2	S1	gas monitoring
Alluvium with peat layers	6	S2	gas monitoring
Sand/gravel (water-bearing)	4	–	–
Chalk	>20	–	–

Table F.2 shows Site A gas monitoring data.

F.2.2 Review of gas monitoring data

The available gas monitoring data indicates peak methane concentrations in the range 0.0% to 2.3% by volume, peak carbon dioxide concentrations in the range 0.2% to 9.0% and steady state emission flow rates of up to 16 L/h and one negative (inflow) flow rate of 35 L/h. In accordance with **6.3.5**, **6.3.6** and **6.3.7**, temporal variability, limitations and the quantity of available data are considered.

In the case of Site A, there are:

- standpipe response zones flooded with groundwater;
- limited number of standpipes;
- only three monitoring occasions – poor temporal coverage; and
- no monitoring in the made ground.

Table F.2 **Site A gas monitoring data**

Date	**BH ID**	**Flow**		**Concentration CH_4**		**Concentration CO_2**		***Qhg* CH_4 (peak)** [A]	***Qhg* CO_2 (peak)** [A]	**Stratum screened**	**Flooded response zone (yes/no)**	**Barometric pressure**
		Peak L/h	**Steady** L/h	**Peak** %	**Steady** %	**Peak** %	**Steady** %					
10/06/2014	BH101	0.0	0.0	0.0	0.0	1.4	1.2	0.000	0.000	AL & S&G	Y	Rising
	BH102	12.0	11.0	1.0	0.9	2.0	1.8	0.110	0.220	AL & S&G	Y	
	BH103	2.0	0.0	0.1	0.0	1.3	1.2	0.000	0.000	AL & S&G	Y	
	BH104	0.5	0.1	0.4	0.3	0.8	0.7	0.000	0.001	AL & S&G	Y	
	BH105	20.0	16.0	0.3	0.2	9.0	8.5	0.048	1.440	AL & S&G	Y	
24/06/2014	BH101	0.1	0.0	0.0	0.0	1.1	1.1	0.000	0.000	AL & S&G	Y	Rising
	BH102	9.0	8.0	0.1	0.1	2.5	2.3	0.008	0.200	AL & S&G	Y	
	BH103	–40.0	-35.0	0.5	0.4	5.5	5.4	–0.175	–1.925	AL & S&G	Y	
	BH104	0.6	0.6	2.1	2.1	0.2	0.2	0.013	0.001	AL & S&G	Y	
	BH105	16.0	15.0	0.8	0.7	5.0	4.5	0.120	0.750	AL & S&G	Y	
08/07/2014	BH101	0.0	0.0	0.1	0.0	1.3	1.2	0.000	0.000	AL & S&G	Y	Falling
	BH102	8.0	7.5	0.3	0.4	2.0	1.8	0.023	0.150	AL & S&G	Y	
	BH103	1.6	1.5	0.1	0.0	1.9	1.2	0.002	0.029	AL & S&G	Y	
	BH104	0.6	0.4	2.3	2.3	0.6	0.6	0.009	0.002	AL & S&G	Y	
	BH105	5.0	4.6	0.4	0.2	2.9	2.9	0.018	0.133	AL & S&G	Y	

[A] Calculated using peak concentration and steady state flow (see **6.3.4**).

NOTE Shaded cells are maximum steady state flow, positive and negative (all standpipes and measurements) and maximum concentrations for methane and carbon dioxide (all standpipes and measurements).

NOTE 1 The standpipes had been installed principally for sampling groundwater in the sand/gravel layer and for monitoring the presence of gas arising from peat layers in the alluvium; the screened section only extended in the sand/gravel layer and the lower (saturated) part of the overlying alluvium layer.

The conclusion of the review is that this gas monitoring data is not reliable to characterize the ground gas conditions.

NOTE 2 If the data had been used, the maximum implied CS derived by combining the maximum observed flow rate and maximum observed concentrations from different boreholes during any monitoring event would have been as in Table F.3.

Table F.3 **Maximum implied CS derived by combining the maximum observed flow rate and maximum observed concentrations from different boreholes during any monitoring event**

Flow rate q L/h	**C_{hg} CH_4** %	**C_{hg} CO_2** %	**Q_{hg} CH_4 ($C_{hg} \times q$)** L/h	**Q_{hg} CO_2 ($C_{hg} \times q$)** L/h	**Implied CH_4 CS**	**Implied CO_2 CS**
16	2.3	9	0.37	1.44	2	3
–35	2.3	9	0.81	3.15	3	3

NOTE Implied CS from Table 2 using Q_{hg} flow rates, although Table 2 is for assigning site (or zone) CS based on site characteristic GSV.

F.2.3 Site A additional standpipe installation and gas monitoring

It is suspected that the high recorded flow rates have been driven by water level changes in the sand and gravel aquifer, and so a set of new standpipes have been installed that are terminated within the lower levels of the alluvium and do not penetrate into the underlying gravel stratum.

The subsequent additional gas monitoring measurements resulting from these supplementary installations, shown in Table F.4, reveal a more consistent picture of the gas regime.

Table F.4 **Site A subsequent additional gas monitoring measurements**

Date	**BH ID**	**Flow**		**Concentration CH_4**		**Concentration CO_2**		***Qhg* CH_4 (peak) $^{A)}$**	***Qhg* CO_2 (peak) $^{A)}$**	**Stratum screened**	**Flooded response Zone (yes/no)**	**Barometric pressure**
		Peak L/h	**Steady** L/h	**Peak** %	**Steady** %	**Peak** %	**Steady** %					
05/08/2014	BH106	0.0	0.0	0.1	0.1	0.6	0.5	0.00	0.00	MG & AL	N	Rising
	BH107	0.1	0.1	0.0	0.0	0.2	0.3	0.00	0.00	MG & AL	N	
	BH108	0.5	0.4	0.3	0.3	9.0	8.5	0.00	0.04	MG & AL	N	
	BH109	0.2	0.2	0.3	0.3	1.2	1.0	0.00	0.00	MG & AL	N	
	BH110	0.0	0.0	0.1	0.0	0.1	0.0	0.00	0.00	MG & AL	N	
02/09/2014	BH106	0.0	0.0	0.1	0.0	0.4	0.2	0.00	0.00	MG & AL	N	Rising
	BH107	0.2	0.2	0.5	0.4	4.0	3.2	0.00	0.01	MG & AL	N	
	BH108	0.0	0.0	0.2	0.1	3.0	2.5	0.00	0.00	MG & AL	N	
	BH109	–0.4	–0.3	0.5	0.4	5.5	5.2	0.00	0.02	MG & AL	N	
	BH110	0.3	0.1	0.0	0.0	0.1	0.0	0.00	0.00	MG & AL	N	
16/09/2014	BH106	0.0	0.0	0.1	0.1	0.4	0.4	0.00	0.00	MG & AL	N	Rising
	BH107	0.3	0.1	0.0	0.0	4.0	3.0	0.00	0.01	MG & AL	N	
	BH108	0.0	0.0	0.0	0.0	0.2	0.1	0.00	0.00	MG & AL	N	
	BH109	0.4	0.2	0.2	0.2	1.4	1.2	0.00	0.00	MG & AL	N	
	BH110	0.8	0.7	0.8	0.5	5.0	4.8	0.01	0.04	MG & AL	N	
30/09/2014	BH106	0.2	0.2	0.1	0.0	2.1	2.0	0.00	0.00	MG & AL	N	Falling
	BH107	1.2	1.1	1.0	0.9	2.0	1.8	0.01	0.02	MG & AL	N	
	BH108	0.0	0.0	0.1	0.0	0.4	0.2	0.00	0.00	MG & AL	N	
	BH109	–0.2	0.1	0.2	0.2	1.0	0.9	0.00	0.00	MG & AL	N	
	BH110	0.4	0.3	0.8	0.5	2.2	2.0	0.00	0.01	MG & AL	N	
14/10/2014	BH106	0.0	0.0	0.0	0.0	0.2	0.1	0.00	0.00	MG & AL	N	Rising
	BH107	0.2	0.1	0.5	0.2	3.5	2.9	0.00	0.00	MG & AL	N	
	BH108	0.1	0.0	0.2	0.2	1.3	1.1	0.00	0.00	MG & AL	N	
	BH109	0.0	0.0	0.9	0.8	2.0	1.8	0.00	0.00	MG & AL	N	
	BH110	0.0	0.0	0.0	0.0	1.0	0.5	0.00	0.00	MG & AL	N	

Table F.4 **Site A subsequent additional gas monitoring measurements**

Date	**BH ID**	**Flow**		**Concentration CH_4**		**Concentration CO_2**		***Qhg* CH_4 (peak)** [A)]	***Qhg* CO_2 (peak)** [A)]	**Stratum screened**	**Flooded response Zone (yes/no)**	**Barometric pressure**
		Peak L/h	**Steady** L/h	**Peak** %	**Steady** %	**Peak** %	**Steady** %					
28/10/2014	BH106	0.1	0.1	0.0	0.0	1.3	1.2	0.00	0.00	MG & AL	N	Rising
	BH107	0.3	0.2	0.2	0.2	1.5	1.4	0.00	0.00	MG & AL	N	
	BH108	0.3	0.1	0.5	0.5	3.5	3.2	0.00	0.00	MG & AL	N	
	BH109	0.2	0.1	0.9	0.6	5.0	4.8	0.00	0.01	MG & AL	N	
	BH110	0.0	0.0	0.2	0.1	1.0	0.8	0.00	0.00	MG & AL	N	

[A)] Calculated using peak concentration and steady state flow (see **6.3.4**).

NOTE Shaded cells are maximum steady state flow and maximum concentrations for methane and carbon dioxide (for each standpipe).

F.2.4 Site A characteristic gas situation (CS) (revised)

The implied maximum CS is derived from consideration of the maximum hazardous gas flow rate calculated from each single borehole standpipe during any of these subsequent monitoring events as shown in Table F.5.

Table F.5 **Implied maximum CS derived from consideration of the maximum hazardous gas flow rate calculated from any single borehole standpipe during any of these subsequent monitoring events**

BH ID	**Flow rate (max.) q**	**C_{hg} CH$_4$**	**C_{hg} CO$_2$**	**Q_{hg} CH$_4$**	**Q_{hg} CO$_2$**	**Implied CH$_4$ CS**	**Implied CO$_2$ CS**
	L/h	%	%	L/h	L/h		
BH106	0.2	0.1	2.1	0.000	0.000	1	1
BH107	1.1	1.0	4.0	0.011	0.044	1	1
BH108	0.4	0.5	9.0	0.002	0.036	1	1
BH109	0.2	0.9	5.5	0.002	0.011	1	1
BH110	0.7	0.8	5.0	0.006	0.035	1	1

NOTE Implied CS from Table 2 using Q_{hg} flow rates, although Table 2 is for assigning site (or zone) CS based on site characteristic GSV.

The worst case CS is derived by combining the maximum observed flow rate and maximum observed concentrations from different boreholes during any of these subsequent monitoring events, as shown in Table F.6.

Table F.6 **Worst case implied CS derived by combining the maximum observed flow rate and maximum observed concentrations from different boreholes during any of these subsequent monitoring events**

Flow rate q	**C_{hg} CH$_4$**	**C_{hg} CO$_2$**	**Q_{hg} CH$_4$ ($C_{hg} \times q$)**	**Q_{hg} CO$_2$ ($C_{hg} \times q$)**	**Implied CH$_4$ CS**	**Implied CO$_2$ CS**
L/h	%	%	L/h	L/h		
1.1	1.0	9.0	0.01	0.10	1	2

NOTE Implied CS from Table 2 using Q_{hg} flow rates, although Table 2 is for assigning site (or zone) CS based on site characteristic GSV.

On the basis of the measurements in Table F.6, the site GSV is taken to be 0.10 L/h, which is the worst case for methane and carbon dioxide. From Table 2, a GSV of 0.10 L/h lies within the range of GSV values for CS2 (0.07 to <0.7), and is not near the upper end of this range. Therefore CS2 is taken as the design gas regime for the site.

Table F.7 shows the Site A gas protection score needed for different building types.

Table F.7 **Minimum gas protection score (points) for different types of building at Site A**

Building type	CS	Minimum score
Conventional residential house, at grade (Type A building)	2	3.5
School and/or hospital, at grade (part Type B and part Type C)	2	3.5 and 2.5
Managed apartments, at grade (Type B building)	2	3.5
Office building with basement (Type C building)	2	2.5
Large floor plan retail/commercial/industrial building, at grade (Type D building)	2	1.5

NOTE Table 4 gives the recommended gas protection score by CS and type of building.

F.2.5 Possible solutions for Site A

Taking into account the planned form of construction of the ground floor slab or basement (the structural barrier), the options for additional ventilation and gas membrane protection measures are considered using the guidance in Clause **7** and Annex A, Annex B and Annex C, to achieve the required minimum score. Solutions for a range of different types and uses of buildings on Site A are presented in Table F.8, for CS2.

Table F.8 **Combinations of measures to provide a gas protection solution for different types of building at Site A**

Type and use of building	Minimum score	Structural Barrier (score)	Ventilation/ dilution (score)	Gas membrane (score)	Total achieved score
Conventional residential house (no basement) (Building Type A)	3.5	Suspended beam and block flooring (0)	Ventilated void (very good performance) (2.5)	Damp proof membrane (DPM) (0)	2.5 (fail)
				Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	4.5 (pass)
School and/or hospital, (no basement) (Partly Building Type B and partly Building Type C)	3.5 (part) and 2.5 (part)	Cast in-situ ground-bearing slab (1)	Low fines gravel blanket with gas drains into gravel trench around building (preferential pathway only) (0.5)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	3.5

Table F.8 **Combinations of measures to provide a gas protection solution for different types of building at Site A**

Type and use of building	Minimum score	Structural Barrier (score)	Ventilation/ dilution (score)	Gas membrane (score)	Total achieved score
Managed apartments, (no basement) (Building Type B)	3.5	Cast in-situ suspended slab (1.5)	Low fines gravel blanket into gravel trench around building (preferential pathway only) (0.5)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	4
Basement area of office building with basement car park and service/store rooms (Building Type C)	2.5	Cast in-situ ground-bearing basement slab (1)	Part well ventilated basement car park (4)	DPM in car parking areas (0)	5
			part poorly ventilated rooms/spaces (0)	Gas resistant membrane (in accordance with all the recommendations in Table 7) in service/store room areas (2)	3
Office building with basement plant rooms (Building Type C)	2.5	Grade2 waterproofed basement (2)	Low fines gravel blanket beneath basement slab and behind all walls (pressure relief pathway) (0.5)	DPM (0)	2.5
Large floor plan retail/commercial/ industrial building (no basement) (Building Type D)	1.5	Cast in-situ ground-bearing slab (1)	6F2 sub-base + geocomposite dispersal layer to low level vents (preferential pathway only) (0.5)	DPM (0)	1.5
		Suspended floor slab (1.5)	Well graded subbase (not pressure relief pathway) (0)	DPM (0)	1.5

F.2.6 Summary and conclusion for Site A

For Site A, it was recognized that an assessment of monitoring data obtained from standpipes with response zones below groundwater level provided an inadequate CSM and, in this case, a possible/probable over-estimate of ground gas risk to the surface development. New monitoring wells were installed. The monitoring period for these new wells was limited to approximately three months, and on all but one monitoring event, atmospheric pressure was rising (which is not when highest emission flow rates would be expected to be measured). Recognizing that this might represent a temporally limited data set, worst case measurements were combined to calculate Q_{hg}. In this case Q_{hg} for carbon dioxide of 0.10 L/h was adopted directly as the derived GSV, rating the site as at the lower end of CS2. This was considered consistent with the CSM, where a no significant gas risk situation (CS1) was judged improbable under all temporal conditions that could be foreseen. Equally, it was considered that extended monitoring would not plausibly result in data requiring the site to be CS3. Adopting CS2 was consistent with the CSM and would result in relatively simple but effective protection against the low gas hazard present.

F.3 Site B

F.3.1 Site B ground conditions and available gas monitoring data

This site includes an area of 1960s landfill within a former gravel pit, which is the area where the buildings are proposed. Records of the types of wastes deposited are limited but indicate a greater proportion of construction and demolition wastes with lesser proportion of household wastes.

Based solely on knowledge of the potential gas source (made ground deposited in 1960s landfill) an experienced assessor is likely to anticipate that the site will be a “low or moderate hazard potential” site (CS2 or CS3).

The ground conditions revealed by a site investigation carried out in accordance with the recommendations in **5.0** are shown in Table F.9.

Table F.9 **Site B ground conditions**

Strata	Thickness m	Gas source	Gas investigation data
Made ground (topsoil, subsoil)	0.6 to 1.5	–	–
Made ground (1960s landfill)	3.2 to 4.5	S1	Gas monitoring
Sand/gravel	0.5 to 0.9	–	–
Clay	>10	–	–

Standpipes have been installed with a response zone through the landfill and extending into the underlying sand/gravel. There is a reasonable amount of gas monitoring data that is not presented in detail in this example. The key measurements are given in **F.3.2**.

F.3.2 Characteristic gas situation (CS) for Site B

A review of the adequacy of the gas monitoring data is undertaken in accordance with **6.3.5**, **6.3.6** and **6.3.7** and is found to be sufficient.

No negative flows were recorded.

The maximum implied CS is derived from consideration of the maximum hazardous gas flow rate calculated from any single borehole during any monitoring event, as shown in Table F.10.

Table F.10 **Maximum implied CS derived from consideration of the maximum hazardous gas flow rate calculated from any single borehole standpipe during any monitoring event**

Flow rate **q** **L/h**	**C_{hg} CH_4** **%**	**C_{hg} CO_2** **%**	**Q_{hg} CH_4** **($C_{hg} \times q$)** **L/h**	**Q_{hg} CO_2** **($C_{hg} \times q$)** **L/h**	**Implied** **CH_4 CS**	**Implied** **CO_2 CS**
4.2	8.1	12.0	0.34	0.50	2	2
0.5	22.0	6.5	0.11	0.03	2	1

NOTE Implied CS from Table 2 using Q_{hg} flow rates, although Table 2 is for assigning site (or zone) CS based on site characteristic GSV.

The worst case implied CS is derived by combining the maximum observed flow rate and maximum observed concentrations from different boreholes during any monitoring event, as shown in Table F.11.

Table F.11 **Worst case implied CS derived by combining the maximum observed flow rate and maximum observed concentrations from different borehole standpipes during any monitoring event**

Flow rate **Q** L/h	**C_{hg} CH_4** %	**C_{hg} CO_2** %	**Q_{hg} CH_4** **($C_{hg} \times q$)** L/h	**Q_{hg} CO_2** **($C_{hg} \times q$)** L/h	**Implied** **CH_4 CS**	**Implied** **CO_2 CS**
4.2	22.0	12	0.92	0.50	3	2

NOTE Implied CS from Table 2 using Qhg flow rates, although Table 2 is for assigning site (or zone) CS based on site characteristic GSV.

On the basis of the measurements, the site GSV is taken to be 0.92 L/h, which is the worst case for methane and carbon dioxide. From Table 2, a GSV of 0.92 L/h lies within the range of GSV values for CS3 (0.7 to <3.5), and is very close to the lower end of this range. Therefore CS3 is taken as the design gas regime for the site but recognized that it is likely to be a conservative designation.

Table F.12 shows the minimum gas protection score for different building types at Site B.

Table F.12 **Minimum gas protection score (points) for different types of building at Site B**

Building type	**CS**	**Minimum score**
Conventional residential house, at grade (Type A building)	3	4.5
School and/or hospital, at grade (Part Type B and part Type C)	3	4 and 3
Managed apartments, at grade (Type B building)	3	4
Office building with basement (Type C building)	3	3
Large floor plan retail/commercial/industrial building, at grade (Type D building)	3	2.5

NOTE Table 4 gives the recommended minimum gas protection score by building type.

F.3.3 Possible solutions for Site B

Taking into account the planned form of construction of the ground floor slab or basement (the structural barrier), the options for additional ventilation and gas membrane protection measures may be considered using the guidance in Clause **7** and Annex A, Annex B and Annex C, to achieve the recommended minimum score. Solutions for a range of different types and uses of buildings on Site B are given in Table F.13, for CS3.

Table F.13 **Combinations of measures[A)] to provide a gas protection solution for different types of building at Site B**

Type and use of building	Minimum score	Structural Barrier (score)	Ventilation/ dilution (score)	Gas Membrane (score)	Total achieved score
Conventional residential house, at grade (Building Type A)	4.5	Suspended beam and block flooring (0)	High voidage polystyrene void former dispersal layer (very good performance) (2.5)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	4.5
School and/or hospital, at grade (partly Building Type B and partly Building Type C)	4 (part) and 3 (part)	Cast in-situ ground-bearing slab (1)	6F2 Sub-base + geocomposite gas dispersal layer with low level vents (good performance) (1.5)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	4.5
Managed apartments, at grade (Building Type B)	4	Cast in-situ reinforced concrete suspended slab (1.5)	No effective ventilation measures (0)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	3.5 (fail)
			With pressure relief measures (0.5)		4 (pass)
Office building with basement car park (Building Type C)	3	Cast in-situ Grade 1 ground-bearing basement slab (1)	Ventilated basement car park (4)	—	5
Basement plant rooms of office building (Building Type C)	3	BS 8102 Grade 2 waterproofed basement (2)	No external ventilation measures (0)	Internally applied asphalt-latex gas resistant membrane (2)	4

Table F.13 **Combinations of measures[A)] to provide a gas protection solution for different types of building at Site B**

Type and use of building	Minimum score	Structural Barrier (score)	Ventilation/ dilution (score)	Gas Membrane (score)	Total achieved score
Large floor plan retail /commercial /industrial building, at grade (Building Type D)	2.5	Cast in-situ ground-bearing slab (1)	No ventilation measures (0)	Gas resistant membrane (in accordance with all the recommendations in Table 7) (2)	3
		Suspended floor slab (1.5)	Low voidage polystyrene void former dispersal layer, low level side vents (good performance) (1.5)	Damp proof membrane (DPM) (0)	3

A) The combinations of measures given in Table F.14 are examples of how the minimum required score could be achieved. Other combinations of measures might be more appropriate for a particular building.

NOTE If the new building is not situated directly over the landfilled area an alternative approach is to delineate the extent of the landfilled area and to introduce an in-ground venting/barrier trench between the landfill and the building site.

Annex G (informative) Radon

G.1 General

This British Standard does not consider the risks associated with radon gas, primarily as the methods of measurement and risk assessment do not align with those for other ground gases. However, as there are similarities in the methodology of mitigation of the effects of the gas Annex G is included to give the reader a background to the subject and suggest further reading and research.

NOTE BS 8576:2013, Annex B also contains information on radon including suggestions as to how it could be measured in the ground.

G.2 Background

Radon is a naturally occurring radioactive gas which decays into other radioactive species. It decays to form a radioactive particle in the air which, when inhaled emits radiation that damages the lungs.

The main danger from high radon exposure is the increased risk of lung cancer. Estimates of radon related deaths have been suggested based on epidemiological information to be up to 2 000 fatal cancers per year.

Radon can move through cracks and fissures in the subsoil and eventually to the atmosphere. Most of the radon disperses harmlessly into the air outside but some passes through the ground and collects in spaces under or within buildings.

Radon is formed by the radioactive decay of the small amounts of uranium present in all rocks and soils. It is commonly present in mine gas and can also be released from groundwater when it is extracted from the ground. It can sometimes be found in significant quantities in private water supplies in areas where there are high levels of radon gas. It can also arise from deposited wastes such as those from the nuclear industry, phosphorus slags, and coal ash. There are published and draft International Standards for investigation and determination of radon in soils (BS ISO 18589, all parts) and in air (BS ISO 11665-1). The latter provides guidance on analysis of historic records, site reconnaissance, identifying preferential migration pathways and development of a sampling plan.

Information and guidance on radon in the environment is available on the Public Health England (PHE) RadonUK website[4]. Also, the Health Protection Agency (now PHE) published advice on radon in 2010 [19].

G.3 Radon in homes

Public Health England recommends that radon levels in homes are less than 200 Becquerel per cubic metre (Bq/m^3). The HPA has also set a target level for domestic properties of 100 Bq/m^3.

The need for protective measures in homes is usually decided by reference to PHE/BGS maps prepared based on an expectation of where radon is likely to be found (essentially the underlying geology) and such measurements as are available [20].

G.4 Radon in the work place

Employers are required by the Management of Health and Safety Regulations at Work 1999 [21] to assess risks from radon in workplaces in radon affected areas. This usually requires a measurement, especially if there is an occupied basement.

NOTE The Health and Safety Executive (HSE) recommends that for occupied below ground workplaces (for example, occupied for more than an average of an hour per week/52 hours per year), or those containing an open water source, the risk assessment includes radon measurements. This applies to all below ground workplaces in the UK, irrespective of the above ground affected areas status.

The Ionising Radiations Regulations 1999 [22] require action to protect employees if the average radon gas concentration exceeds 400 Bq/m^3 in air (see the Note to **G.4**). All below ground workplaces require a risk assessment regardless of whether or not they are in an affected area and the HSE recommend all occupied basements in workplaces are tested. The HSE and local authorities, as appropriate, are responsible for ensuring and supporting compliance with this action including installation of protective measures in existing properties when they are required. The Building Research Establishment (BRE) has published guidance for building owners and managers [23].

G.5 Protection against radon in buildings

The design of measures for protection from radon in residential developments employs the same approach as for the exclusion of other ground gases with the incorporation of a membrane in the construction of the floor and a ventilated under-floor void (often involving an extraction sump for future activation if necessary). These installations require at least as rigorous testing and verification as those intended to provide protection against permanent gases or VOCs. Particularly as the volume of radon which needs to get through the protection system to reach the 200 Bq/m^3 level is much lower than the volume that would be of concern in respect of methane or carbon dioxide.

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[4] www.radonuk.org [last accessed 18 June 2015].

The Building Research Establishment (BRE) has published a series of guidance documents on the protection of buildings against radon (see [24] to [39]).

G.6 Radon and protective measures for other permanent gases

Protective measures against methane and carbon dioxide that have been properly designed, installed and verified in accordance with this standard are protective against most other permanent gases including radon. The exception might be gases with particularly small molecular radii such as hydrogen.

In contrast, no assumptions can be made about measures installed to protect against radon being also protective against methane and carbon dioxide even when properly installed and verified. This is primarily because the membrane employed might not fulfil the requirements for a gas resistant membrane (as defined in **3.3**).

BR211 [24] includes protocols and maps for determining the level of radon protection required for a particular site. Two levels of protection are recognized: basic radon protection and full radon protection. Basic radon protection can be provided by a well-installed DPM modified and extended to form a radon barrier across the ground floor of the building. Full radon protection comprises a radon barrier across the ground floor supplemented by provision of subfloor depressurization or ventilation (either a radon sump or ventilated subfloor void).

Annex H (informative) Volatile organic compounds (VOCs)

H.1 General

This British Standard does not consider the risks associated with VOC gases, primarily as the methods of measurement and risk assessment do not fully align with those for other ground gases (see BS 8576). However, as there are similarities in the methodology for mitigation of the effects of VOCs entering indoor or ambient air spaces, this Annex is included to give the reader a background to the subject and to suggest further reading.

H.2 Background

VOCs are organic compounds that are volatile under normal environmental/atmospheric conditions, although they can sometimes be found in the ground as solid, liquid and dissolved phases as well as in the gaseous phase.

NOTE 1 A VOC can also be defined as an organic compound which is liquid at 20 °C and which generally has a boiling point below 180 °C (see BS EN ISO 11074).

NOTE 2 Examples include single-ring aromatic hydrocarbons and other low boiling halogenated hydrocarbons, which are used as solvents or fuels, and some degradation products.

Volatile organic compounds include:

- halogenated hydrocarbons such as trichloroethene;
- non-halogenated hydrocarbons such as benzene; and
- organosulfur compounds such as thiols (mercaptans).

They can occur as a component of ground gas originating from historically contaminated ground, spills and leaks from industry, commercial or residential properties (e.g. from pipelines, storage facilities, and at the point of use).

H.3 Measurement and Assessment

The behaviour and transport of VOCs in the gaseous phase can be different from that of carbon dioxide and methane, and therefore the methods of measurement and risk assessment are not the same. Guidance on the measurement of VOCs in ground gas can be found in BS 8576, and on the assessment of risks from VOCs in *CIRIA Report C682* [40] and *Updated Technical Background to the CLEA Model* [41].

H.4 Protection

Protection of end users from VOCs can be achieved by treating the source of the VOCs, managing the pathway between the VOC source and the receptor, by managing the receptor or a combination of methods. *CIRIA Report C716* [42] provides an overview of the techniques available for treating or managing the risk presented by VOCs. The methods commonly used to mitigate the risks from VOCs by managing the pathway(s) are similar to the mitigation methods used to manage the risks presented by other gases including carbon dioxide and methane. Both in-ground and in-structure pathway management techniques can be used. In addition within buildings and other structures, it might also be possible to adjust pressure differences to reduce vapour intrusion.

As with other gases, common methods of in-structure pathway management include the incorporation of a membrane in the construction of the floor and a ventilated under-floor void. However, there are important differences between VOCs and other gases. These include:

- the number of different VOCs that might be present, singly or together, in ground gas;
- the fact that many VOCs undergo degradation during transport from the subsurface to the point of exposure, which can be difficult to account for in modelling; and
- that risks can in some cases be presented by very low concentrations of VOCs (see *CIRIA Report C716* [42]).

Due to these differences, there is no easy way to determine the number of levels of in-structure protection that are needed to reduce the risk to an acceptable level. Instead the design needs to take into consideration the effectiveness of the remediation solution (e.g. what has been done to remove or control the source), the confidence in the site characterization and quantitative risk assessment, and the number of lines of evidence for a risk being presented by the vapour intrusion pathway.

Gas resistant membranes are routinely used within the construction industry to reduce the ingress of permanent gases into buildings. It seems reasonable, therefore, to ascertain whether gas resistant membranes as defined in **3.3** provide protection against VOCs and whether, if protection measures including a gas resistant membrane are to be installed, these also provide protection against VOCs.

There are no simple answers to these questions and decisions usually need to be made on a site-specific basis taking into account of, for example, the VOCs present, their concentrations, and the nature of the membrane (e.g. material(s) from which it is manufactured, physical properties thickness) and supplementary materials (e.g. adhesives and sealants).

Individual VOCs can variously permeate through, be absorbed by (sometimes causing swelling), and degrade and change the physical properties of membrane materials. Consideration of whether a membrane provides protection against VOCs is made more difficult because they are rarely found in the sub-surface as a single compound and are more typically found as a mixture of different compounds.

The membrane has not only to prevent the entry of VOCs in the short-term but to remain effective for the design life of the building, i.e. remain durable. Degradation of the membrane can occur over a prolonged period of exposure rather than in the short-term.

Individual polymers permit particular VOCs to permeate them depending upon how chemically similar they are to the challenge compound. For example, although HDPE does not permit the passage of carbon dioxide and methane, VOCs can migrate through it at a rate that is quite high, taking into account the allowable concentrations of those vapours inside buildings.

Specific chemical-resistant membranes with a higher degree of resistance to either degradation or corrosion are available. These types of membrane are specifically designed for use in-ground where the membrane may be in contact with chemicals at high concentrations (*CIRIA Report C716* [42]) either as a separate phase liquid or dissolved in groundwater or a non-aqueous phase liquid; for example, VOCs can dissolve in non-volatile hydrocarbons.

Specific chemical-resistant membranes are not necessarily needed in all scenarios; for example, where located above floor slab and ventilated sub-floor void. Modelling demonstrates that the risks can be appropriately managed with this construction. However, where high concentrations of VOCs in gaseous form are anticipated, the suitability of any membrane that might be used needs careful consideration.

As with permanent gases, the quality of installation of the membrane is a determining factor in how well the installed membrane prevents VOC ingress into the building. Poor installation practices can cause tears or punctures in the membrane. Tears and punctures can increase considerably the VOC flow rate through the membrane as the VOC can move via a convective flow mechanism as well as the normal diffusive flow mechanism. As noted above, VOCs can also degrade adhesives and sealants, and particular care is needed if these are used.

Foamed polystyrene and HDPE geocomposite void formers are sometimes used to provide a sub-floor gas dispersal layer. If VOCs are present, it is important that the void former selected is not chemically degraded by the VOC.

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