PAS 95:2011

Hypoxic air fire prevention systems – Specification

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Foreword

This Publicly Available Specification (PAS) was sponsored by the following companies: AcecoTI, Colorado Altitude Training, COWI, FirePASS Group, Hypoxic Technologies, LPG Fire, Opsys, Prevenex Europe and Wagner Group – all members of the Summit Air Institute for Preservation, Health and Safety (SAIPHS). Its development was facilitated by the British Standards Institution (BSI). It came into effect on 16 November 2011.

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- FirePASS Group.
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- The Altitude Centre.
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The provisions of this PAS are presented in roman type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

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

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Introduction

0.1 General

Hypoxic air fire prevention systems provide a means of inhibiting the development of flaming fires and thus of preventing fires from causing significant damage. They differ from fire-extinguishing systems in that they provide a continuous level of prevention rather than a discharge of extinguishing agent once a fire has been detected.

Normal air is a mixture of oxygen and nitrogen, together with small quantities of argon, carbon dioxide and other gases. Oxygen is the critical element that supports both life and combustion. When the oxygen content is intentionally lowered for special applications, the resulting gas is called hypoxic air or reduced-oxygen air.

Hypoxic air environments are used for physical training and rehabilitation of athletes and in medical research. Fire prevention is another, more recent and evolving application for such systems; Annex A details the concept.

Hypoxic air fire prevention systems are applied in installations where it is possible to control the environment of the protected spaces, either exclusively for fire prevention or in combination with other indoor climate control (e.g. temperature, humidity). They may be used in, for example, archives, vaults, computer facilities, warehousing and cold storage.

Hypoxic air fire prevention systems used in the protection of artefacts and other materials affected by oxidation (e.g. food, paper, paintings, metals) can reduce oxidative degradation.

0.2 Health and safety

Hypoxic environments created for the purpose of fire prevention are precisely controlled and monitored reduced-oxygen environments that should not be confused with other environments where hypoxic conditions can occur in an uncontrolled, unwanted or unexpected way. Hypoxic air fire prevention systems are "clean air" systems based on adjustment of the partial pressure of oxygen, and the atmosphere produced in the protected spaces is essentially the same in character as atmospheres found at altitude and in commercial aircraft cabins.

However, all hypoxic environments are potentially dangerous, and precautions need to be taken if it is intended to have people enter such environments to undertake activities. Low oxygen levels are hard to detect without appropriate monitoring, and there is serious danger to human life where this is not done correctly. Therefore, all people entering a hypoxic environment should be made aware of the reduced oxygen level, of the risks and of the safeguards and the need to stick to them. They should know what the low-oxygen emergency alarm sounds like.

As hypoxic fire-protected spaces are enclosed environments, they are subject, in the UK, to *The Confined Spaces Regulations 1997*. Accordingly, each hypoxic air fire prevention system installation has to undergo a suitably detailed hazard and risk assessment, sufficient to meet the requirements of *The Management of Health and Safety at Work Regulations 1999*, including consideration of the suitability of such a system for the specific application at its location and any protective measures required for the health and safety of all individual people having access to the protected space for all activities to be undertaken.

The Confined Spaces Regulations 1997 detail the safeguards to be taken when working in enclosed spaces, and this PAS details some of the precautions to be taken when dealing with hypoxic air fire-protected spaces. These precautions are determined by the level of oxygen within the protected space and the kind of activities to be undertaken there. As noted, more strenuous activities will require a higher oxygen intake, which may be harder to achieve in a hypoxic environment.

As oxygen levels reduce, so it becomes increasingly important to have adequate provisions in place to protect the health and safety of all people in hypoxic air fire-protected spaces, especially those who may be predisposed to be adversely affected by reduced oxygen levels, such as pregnant women or those with certain medical conditions. Activity levels that have minimal impact on people at higher oxygen levels can have more significant impact at reduced oxygen levels, and so the health implications of raised activity levels in hypoxic environments need to be considered for all individual people entering such an environment.

In atmospheres of reduced oxygen concentration levels, the suitably detailed and sufficient hazard and risk assessment may require people to use breathing apparatus routinely or for specific activities and/or in emergency situations.

1 Scope

This Publicly Available Specification (PAS) specifies requirements for the design, installation, testing and maintenance of hypoxic air fire prevention systems in protected spaces.

This PAS defines the limits of use of such systems.

This PAS is not applicable for fire-extinguishing systems covered by the BS EN 15004 series.

This PAS does not contain recommendations relating to the suitability of hypoxic air fire prevention systems for particular applications or the selection of such systems in the context of the overall fire risk.

2 Normative references

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

BS 5839-1:2002+A2:2008, *Fire detection and fire alarm systems for buildings. Code of practice for system design, installation, commissioning and maintenance*, Clause **25**

BS EN 54-4, *Fire detection and fire alarm systems. Power supply equipment*

BS EN 61508, *Functional safety of electrical/electronic/ programmable electronic safety-related systems. Requirements for electrical/electronic/programmable electronic safety-related systems*

BS EN 15004-1, *Fixed firefighting systems – Gas extinguishing systems – Part 1: Design, installation and maintenance*

3 Terms and definitions

For the purpose of this PAS, the following terms and definitions apply.

3.1 air separation system

system capable of adjusting and controlling the chemical composition of air

3.2 competent person

individual (or organization) that has the requisite training and experience, can access the requisite tools, equipment and information, and is capable of carrying out a defined task to a specified standard

3.3 control panel

component that receives and sends signals to other components of the system (e.g. building management system, fire detection alarm system), with control, monitoring and measurement functions, and alarm and annunciation features, to maintain the design oxygen concentration level in the hypoxic environment of the protected space

3.4 design oxygen concentration level

oxygen concentration level in percentage by volume used as the design basis for a hypoxic air fire prevention system specification for a particular application

***NOTE** The design oxygen concentration level cycles between minimum and maximum values as the hypoxic air fire protection system maintains the hypoxic environment. The range between the minimum and maximum values defines the design operating range of the system for the particular application.*

3.5 flushing

process during which the air separator system is shut down and the air in the protected space is replaced with fresh air

3.6 hold time

period of time that the oxygen concentration level in a protected space remains at or below the maximum oxygen concentration level after the hypoxic air fire prevention system has been shut down

3.7 hypoxic air

air in which the oxygen concentration level has been artificially reduced from its normal level for a specific purpose

3.8 hypoxic air fire prevention system

system designed to create and maintain a hypoxic environment to prevent or inhibit fire

3.9 hypoxic air generator

air separation system that produces hypoxic air with an oxygen concentration level greater than 10% by volume

3.10 ignition-limiting oxygen threshold

oxygen concentration required to limit ignition and prevent sustained flaming combustion of materials when tested in accordance with specified standard procedures

***NOTE** Annex B specifies the test method.*

3.11 indoor air climate (of the hypoxic air fire prevention system)

operating climate, taking into account fresh air composition (normally exclusively via the hypoxic air fire prevention system), temperature and humidity

3.12 infiltration

uncontrolled passage of external air into the protected space through unintended leaks (e.g. cracks between wall sections, roof–wall interface, around windows and doors)

***NOTE 1** Infiltration is often expressed as a percentage of the volume of the protected space per hour.*

***NOTE 2** The test methods described in ISO 16000-8:2007 and the equivalent NT VVS 118:1997 are suitable means of measuring infiltration under non-pressurized conditions. Room integrity test methods using a pressure differential cannot be applied without a valid calculation to correct for influence of pressure.*

3.13 nitrogen injection system

air separation system that produces an output with an oxygen concentration level less than 10% by volume

3.14 normobaric air pressure

atmospheric air pressure at sea level

3.15 normoxic air

air having an oxygen concentration level of 20.9% by volume

3.16 operator

natural or legal person (or organization) having authority for the use and technical operation of the hypoxic air fire prevention system (as designated in the system logbook)

3.17 oxygen alarm level

oxygen concentration level at the maximum or minimum of the allowable range of oxygen concentration levels, beyond the oxygen monitoring system's tolerance, specified for fire prevention in the protected space and that triggers an alarm

3.18 oxygen monitoring system

automatic electronic system capable of measuring the oxygen concentration level within a hypoxic environment

***NOTE** The oxygen monitoring system can be equipped with chemical, electrochemical, infrared, ultrasonic or other types of sensors allowing reliable oxygen monitoring.*

3.19 protected space

enclosed space containing the hypoxic environment

3.20 safety factor

oxygen concentration level reduction (minimum 1% by volume) from the ignition-limiting oxygen threshold

3.21 tolerance

explicit range of allowed values within the oxygen monitoring system's measurements

4 Use and limitations

4.1 General

The design, installation, testing and maintenance of hypoxic air fire prevention systems shall be performed by competent persons.

4.2 Limitations on installation

Hypoxic air fire prevention systems shall not be installed for use in areas where:

a) sufficient infiltration control cannot be achieved;

b) an alternative source of oxygen is present;

c) oxidizing agents exist that have the potential to reduce oxygen concentration by chemical reaction (e.g. chlorine);

d) substances or processes exist that evolve gases capable of modifying the atmosphere such that the oxygen concentration is reduced (e.g. toxic displacement);

e) the hazard and risk assessment (see **4.3**) identifies any other contraindication to their use.

4.3 Hazard and risk assessment

Design and installation of hypoxic air fire prevention systems shall follow a suitably detailed hazard and risk assessment, including consideration of the suitability of such a system for the specific application at its location and any protective measures required for the health and safety of all persons having access to the protected space.

NOTE 1 *Hypoxic air fire prevention systems should not be used in conjunction with smoke control systems.*

NOTE 2 *A hypoxic environment cannot prevent non-oxidizing smouldering or pyrolysis.*

NOTE 3 *Hypoxic air fire prevention systems may not offer full protection in the following areas:*

a) where explosive gases (or explosive mixtures of gases), particulates and liquids are present, or where there is the possibility of explosive atmospheres being created within the range of system operating oxygen concentration levels;

b) where reactive metals, gunpowder, metal hydrides, hydrazine and other chemicals capable of autothermal decomposition are handled or stored;

c) where chemicals containing oxygen available for combustion (e.g. cellulose nitrate) are present.

5 System design

5.1 Planning

The following objectives shall form the basis of the planning process:

a) to create and maintain an environment in the protected space that is effective in preventing fire;

b) to create a hypoxic environment that does not pose a risk to persons.

5.2 Provisions

The design of the hypoxic air fire prevention system and of its programme of operation shall include provision for:

a) access control to prevent unauthorized access to the protected space;

b) coordination and integration with the fire safety strategy for the building and protected space;

c) integration with other systems within the building and with the building itself (e.g. fire alarm, building management, ventilation, environmental);

d) where the system is integrated into an air-conditioning system utilizing remote air-handling units (AHUs) that serve the protected space, air tightness of the ductwork and the AHUs that may contribute to the infiltration;

e) modification of the physical construction of the protected space (e.g. building, room), by sealing or other techniques, to enable retention of the hypoxic environment so as to meet the maximum allowable infiltration of external non-hypoxic air as specified by the system designer;

f) detection of non-oxidizing smouldering or pyrolyzing processes that can occur in the hypoxic air environment by means of a high-sensitivity smoke detection system, taking into account the airflows, possible ignition and restrained combustion scenarios within the protected space;

***NOTE** An example is an overheating cable with pyrolysis of the plasticizer coating: a flaming fire will not develop from this in a correctly designed hypoxic air environment, but detection of the event is desirable to signal and enable remedial action.*

g) assessment of infiltration, taking into account the access requirements of persons, the function and behaviour of all ventilation and environment control systems, and any other features or systems that may impact on the retention of the hypoxic environment;

h) construction of the protected space in such a way that it presents a barrier to fire spreading from adjacent non-protected spaces for a time period determined by local regulations or the building fire safety strategy;

i) air locks or space interfaces to prevent infiltration through access events;

j) flushing in the event of toxic or harmful gases accumulating. In such cases, a hypoxic air fire prevention system installation shall not be appropriate unless the system can be shown to negate the creation of hazardous concentrations;

***NOTE** The capability for flushing should be designed into the hypoxic air fire prevention system only if approval is obtained from the local fire service. In addition, prior to flushing, insurers should be notified in the same way as when a sprinkler system is impaired or taken offline.*

k) making all data relating to the design oxygen concentration level, in conjunction with the duration of time persons will spend in the protected space and the level of activity undertaken while there, available for incorporation into the health and safety policy;

l) determining the design oxygen concentration level appropriate to the types of "reasonable worst case" materials to be found in the protected space;

***NOTE 1** If materials present are unknown, the efficiency of this protection approach cannot be assured.*

***NOTE 2** Some combustibles contain variable amounts of chemically bonded oxygen, some may contain normal air in pockets (e.g. bubble wrap), and stored combustibles may be plastic wrapped. The combustibles should be assessed by ignition-limiting oxygen threshold and behaviour in defined tests (see Annex B).*

m) the type of air separation system used, together with any methods used to provide homogeneity of the hypoxic environment and to confirm that all required areas are protected;

n) considerations related to discarding high-oxygen by-product from the hypoxic air generator, where used, including the increased fire risk from the high-oxygen discharge;

NOTE The high-oxygen by-product is usually vented to the atmosphere but could be used for other purposes.

o) consideration of the acoustic impact;

p) management of compressor heat and condensate produced by the air separation system, where used;

NOTE Where possible, arrangements should be made to utilize the heat generated by the process of compression.

q) consideration of compressor power consumption.

5.3 System design specification

The design specification for the hypoxic air fire prevention system and for its programme of operation shall include:

a) access control, which shall be provided according to the system classification requirements of **6.2**;

b) the total volume of the protected space, together with the number and shape (dimensions) of rooms comprising that protected space;

c) the design oxygen concentration level to reflect the fire prevention requirements based on the combustible contents. The maximum design oxygen concentration level shall be at least 1% lower than the ignition-limiting oxygen threshold, allowing for any measurement tolerance of the oxygen monitoring system;

d) the operating range of design oxygen concentration levels (i.e. defined maximum and minimum values, within the tolerance of the oxygen monitoring system);

e) the infiltration, together with the method of assessment. The infiltration shall be expressed in percentage infiltration of room volume per hour (e.g. an infiltration of 1.5% of room volume per hour);

NOTE 1 An estimate can be made of the infiltration (e.g. in the case where the protected space has yet to be constructed). The built environment can be verified by an approved test method for measuring infiltration under non-pressurized conditions, as in ISO 16000-8:2007 or the equivalent NT VVS 118:1997.

NOTE 2 A method for verifying the system design to compensate for infiltration should be demonstrated. This is likely to be a direct measurement of the rate of oxygen concentration level increase versus the air separation system output.

NOTE 3 Infiltration measurements used in the testing of building infiltration are measured at a 50 Pa pressure differential, as defined in BS EN 13829. This does not equate to infiltration at 0 Pa pressure differential. If this method is used, proof of correlation should be provided to ensure design equivalence.

f) the documented altitude of the protected space. The equivalent oxygen concentration at this altitude shall be subtracted from the minimum design oxygen concentration level and oxygen monitoring system tolerance to determine the system classification (see **6.2**). In doing so, consideration shall be made that, for every 410–450 metres above sea level, the available oxygen for respiratory purposes reduces by 1% by volume relative to that available at sea level;

g) the classification of the system (see **6.2**), which shall be documented;

h) the type and arrangement of the oxygen monitoring system. This shall include oxygen sensor tolerance; power consumption; service life; suitable operating atmosphere to prevent poisoning; calibration method; calibration and test periodicity; drift characteristics; and specific self-compensation for calibration and drifting. The oxygen monitoring system shall comply with the requirements of BS EN 61508;

i) at least two oxygen monitoring sensors for each protected space. These devices shall be capable of initiating system alarms and shall be powered from independent supplies with 24-hour back-up in accordance with BS 5839-1+A2:2008, Clause **25**;

j) a clearly defined method to ensure adequate mixing of the environment. Where one or more air movers, if required, have the potential to fail, thus affecting the homogeneity of the hypoxic air fire prevention system, the system shall be designed with provision for redundancy;

k) the types, pressure ratings, sizes and fire ratings of distribution pipework. Pipework and fittings shall be pressure rated to 1.5 times working pressure;

l) the performance data of the air separation system. These shall include flow rate (litres/minute), oxygen concentration level (%), compressor power consumption (kW), the costs of the energy likely to be used by the system, maintenance intervals and its service life;

m) the time to achieve the maximum and minimum design oxygen concentration level from start-up (hours);

n) the duty cycle of the system. The maximum duty cycle shall be 75%;

NOTE The duty cycle is the percentage of time that the air separation system is active during the operation of the hypoxic air fire prevention system. A graphical representation of the duty cycle of a hypoxic air fire prevention system, with example system performance data, is given in Figure 1.

o) the hold time, which shall be no less than 30 minutes. Where longer hold times are required then there shall be a provision for a redundant hypoxic air supply (e.g. additional compressor and/ or a standby power supply);

NOTE A graphical representation of hold time is given in Figure 2.

p) alarms and status outputs, local and remote. The minimum alarm levels shall be low oxygen (human safety), high oxygen (loss of fire prevention) and fault in the oxygen monitoring system;

q) automatic disabling of hypoxic air input in the event of the operation of a low-oxygen alarm, to avoid the risk of further reductions in oxygen concentration;

NOTE This action may lead to disability of the hypoxic air fire prevention system.

r) the types and sizes of control and sensor cables. Sensor cables outside the protected space shall be fire rated for two hours;

s) the ventilation and cooling requirements and space for the air separation system. The heat generation and required air input supply shall be documented. The maximum and minimum temperature of the air separation system shall be documented and shall be within operating limits of all associated components. The air input required shall be documented, and the requisite amount and rate of air supply shall be provided;

NOTE Compressors generate large amounts of heat that can be used as a secondary heat source and/or needs to be removed from the area. Compressors require air input supply; restrictions of this supply can reduce compressor performance and prevent correct system operation, as well as increase noise of compressor operation

t) the operating noise of the compressor and air input points, which shall be documented;

u) the requirements for access to the protected space (e.g. for persons and the nature and size of openings for this), including the infiltration implications of such openings;

NOTE this requires a knowledge of the differential pressure or linear airflow, to enable a volumetric calculation of inward air infiltration caused through each access event. This value should be added to the background infiltration to give a total infiltration value.

v) the system data-logging capability and communications protocol for external systems;

w) the methods employed to provide for the health and safety of persons occupying the protected space;

x) the dimensions (m) and mass (kg) of major components;

y) techniques to prevent unauthorized adjustment of oxygen and alarm level settings (e.g. mechanical or electronic access restrictions). These shall be documented;

z) installation instructions and commissioning procedures for the system;

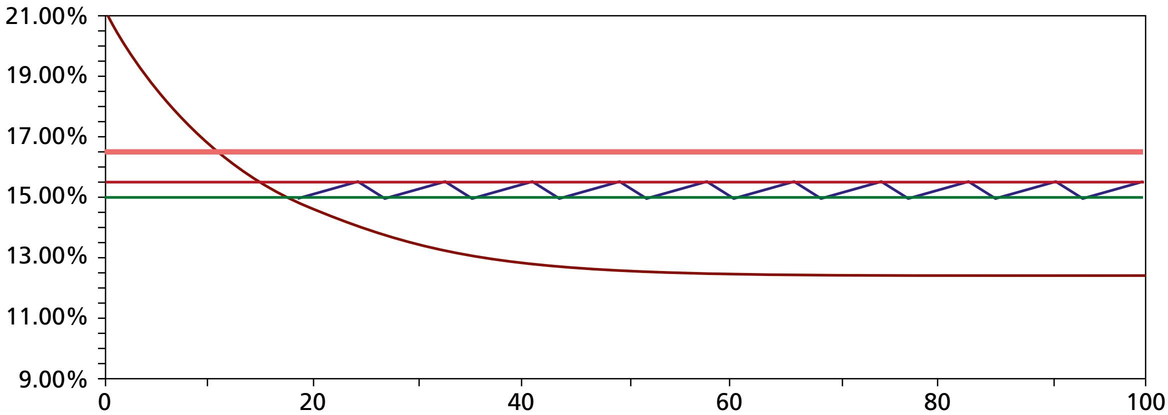
aa) operational and servicing requirements (including records required);

ab) an emergency plan, including detailed instructions for operational procedures in the case of low-oxygen alarm (to cover safety of persons) and high-oxygen alarm or system failure (to cover loss of fire prevention);

ac) warning signs indicating a controlled low-oxygen space and the lowest design oxygen concentration level to be installed, at all entrances to the protected space (see **6.2**).

Figure 1 – Graphical representation of the duty cycle of a hypoxic air fire prevention system, with example system performance data

In this example, the oxygen concentration level in the protected space is initially 20.9%. The air separation system starts feeding low-oxygen air into the protected space, and the oxygen concentration level diminishes until the minimum design oxygen concentration level is achieved. At that point the air separation system stops feeding the room, and the oxygen concentration level in the protected space starts rising due to infiltration. When it reaches the maximum design oxygen concentration level, the air separation system starts again, feeding low-oxygen air into the protected space until the minimum design oxygen level concentration is once more achieved. In this way, the oxygen concentration level in the protected space is always kept between the minimum and the maximum design oxygen concentration levels.



Y-axis – Oxygen concentration level (% by volume)
X-axis – Time (hours)

Key:

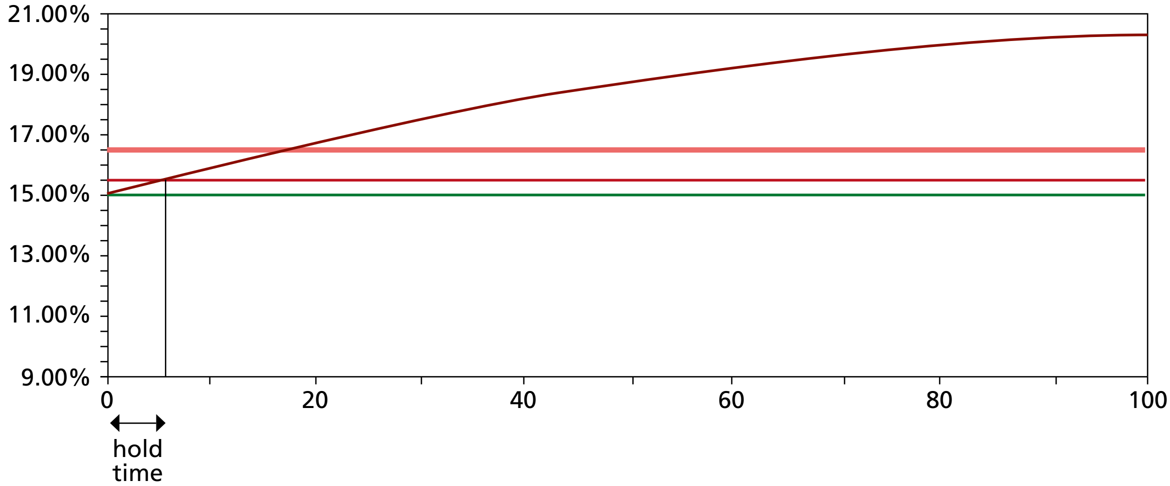
Dark red	*Oxygen concentration level in continuous system operation without duty cycling between the minimum and maximum design oxygen concentration levels*
Light red	*Maximum design oxygen concentration level*
Green	*Minimum design oxygen concentration level*
Pink	*Ignition-limiting oxygen threshold*
Blue	*Oxygen concentration level in normal system operation with duty cycling between the minimum and maximum design oxygen concentration levels*

System data example for Figure 1

Room volume	*770 m³ (770,000 litres)*
Infiltration of ambient air	*1.5% of room volume per hour (192.5 litres/hour)*
Output of the air separation system	*750 litres/minute, equivalent to 5.8% of room volume per hour (140% per day). This requires a compressor output of 1,485 litres/minute*
Oxygen content in the output of the air separation system	*10%*
Starting oxygen concentration level	*20.9%*
Minimum design oxygen concentration level	*15%*
Maximum design oxygen concentration level	*15.5%*
Ignition-limiting oxygen threshold	*16.5%*
Duty cycle of the air separation system	*33%*

Figure 2 – Graphical representation of hold time

In this example, the air separation system has been switched off at the start, and the oxygen concentration level in the protected space increases as a result of infiltration. The protected space remains protected against fire until the ignition-limiting oxygen threshold is reached. The amount of time taken to reach the maximum design oxygen concentration level, the hold time, will depend on the oxygen concentration level in the protected space at the time the air separation system is shut down.



Y-axis – Oxygen concentration level (% by volume)

X-axis – Time (hours)

Key:

Dark red	*Oxygen concentration level from system switch-off at time zero*
Green	*Minimum design oxygen concentration level*
Light red	*Maximum design oxygen concentration level*
Pink	*Ignition-limiting oxygen threshold*

5.4 Control panel

All control panel alarms shall be available to connect to a remote central supervisory centre.

The control panel shall incorporate a standard communications protocol (e.g. RS 485) to allow effective interfacing with other fire and building management systems and for the collection and storage of system performance data.

The control panel shall include, as a minimum:

a) continuous display of the oxygen concentration level measured in each protected space;
b) alarm indications at oxygen alarm levels measured on any of the oxygen sensors in the protected area;
c) oxygen sensor fault;
d) fault status indication (e.g. abnormal pressure in the air separation system);
e) online/offline status controlled by a secure switch;
f) control of the range of oxygen concentration levels acceptable for each room in the protected space and the associated alarms, with appropriate safeguards so that levels cannot be accidentally adjusted;
g) a power supply that conforms to BS EN 54-4, with sufficient battery backup for 24 hours in the event of mains failure.

Low oxygen concentration level alarm shall trigger automatic shutdown.

5.5 Indoor air climate

Consideration shall be given in the system design to the impact on temperature and humidity of the hypoxic air fire prevention system, with due regard to the requirements of the application of the protected space (e.g. control of humidity for storage of books).

NOTE *A hypoxic air fire prevention system may be installed, subject to the design specification being met, as a component of the air-conditioning system.*

5.6 Flushing

The system design shall allow for flushing when necessary, with the following instructions given to the operator:

- the period of any loss of fire protection and the time to restore is to be documented;
- flushing is to be undertaken only by a competent person;
- flushing is to be undertaken to restore an acceptable air quality no more frequently than is necessary.

NOTE 1 *Flushing is necessary where the application of the protected space adversely affects air quality.*

NOTE 2 *Flushing can be done in various ways, including opening doors/windows and using a ventilation system. The duration of flushing will depend on the mechanism and size of the hypoxic environment.*

NOTE 3 *The frequency of flushing (if any) will be dependent on the material stored, and so no timetable can be provided in this specification.*

NOTE 4 *Due to the possible loss of fire prevention; flushing should be avoided as far as possible. Alternative fire protection methods (e.g. fire watch) should be put in place before the hypoxic air environment is removed.*

5.7 Oxygen monitoring

The system design shall enable the oxygen concentration level to be monitored on a continual basis by a minimum of two independent oxygen sensors in different locations in each protected space. These shall transmit to monitoring and control points (e.g. the fire alarm panel and the building management system), as required.

The location of the sensors shall be such as to not be influenced by the injection of hypoxic air or nitrogen. The readings from the sensors shall reflect the homogeneity of the hypoxic air environment.

Performance indicators shall show, as a minimum for each protected space:

a) oxygen concentration level as indicated by every oxygen sensor;
b) high- and low-oxygen alarm conditions;
c) an output indicating the operation of any other system alarms (e.g. oxygen sensor fault).

The monitoring system shall comply with BS EN 61508 and the requirements of **5.3**.

5.8 Data retention

The system design shall enable the following data to be recorded and stored for a minimum of 12 months:

a) oxygen concentration levels (minimum every 10 minutes);
b) alarms (event-driven);
c) duty cycle (event-driven);
d) faults (event-driven).

A method shall be provided to retrieve information for analysis without compromising existing storage or continuing data storage. Where this storage is not provided by external systems such as the building management system, the hypoxic air fire prevention system shall incorporate storage of this information.

NOTE *An event is an alarm or fault condition attained at a preconfigured value.*

6 Hazard and risk assessment, system classification and health and safety

6.1 Hazard and risk assessment

Hypoxic air fire prevention systems shall be installed for use in locations only where a sufficient hazard and risk assessment has been carried out to:

a) justify installation and use of a hypoxic air fire prevention system at a particular location rather than conventional fire protection for the specific application and classification of the risk(s);

b) enable provision of protective measures for the health and safety of all persons having access to the protected space;

c) identify the number of people in the protected space and the physiological requirements of the activities to be undertaken.

NOTE 1 *As the protected spaces are enclosed hypoxic environments, they are subject, in the UK, to* The Confined Spaces Regulations 1997. *The hazard and risk assessment should be sufficient to meet the requirements of* The Management of Health and Safety at Work Regulations 1999. *The Health and Safety Executive (HSE) document L101,* Safe work in confined spaces. Approved Code of Practice, Regulations and guidance, *is available as a free download from the HSE website: http://www.hse.gov.uk/pubns/books/l101.htm*

NOTE 2 *There are three physiological factors that define the risk, if any, posed by hypoxic environments to healthy persons occupying them:*

a) oxygen partial pressure (the combined effect of air pressure and the proportion of oxygen in it);

b) duration of exposure;

c) the level of exertion required to carry out any task.

An additional important factor is whether the person is able to leave the protected space unassisted at any time or not.

6.2 System classification and minimum safety requirements

The design oxygen concentration level shall be used to determine the system classification and minimum health and safety requirements for people in the protected space as follows:

a) the maximum design oxygen concentration level (D_{max}) shall be calculated by subtracting from the ignition-limiting oxygen threshold (I) a safety factor (S) (minimum 1%) and the oxygen monitoring system tolerance (O):
$D_{max} = I – S – O$;

b) from the calculated maximum design oxygen concentration level, the system design operating range shall determine the minimum design oxygen concentration level (D_{min});

c) an altitude correction factor (A) shall be subtracted from the minimum design oxygen concentration level, to determine the oxygen level on which the system classification shall be based (D_{sys}):
$D_{sys} = D_{min} – A$.

The system classifications and associated minimum signage, alarms and access control measures in Table 1 (see over) shall apply, unless the hazard and risk assessment (see **6.1**) requires otherwise.

Identification of people predisposed to be affected by reduced-oxygen conditions shall be undertaken so that access or activity restrictions can be applied.

NOTE *The calculation of the system classification presented in Table 1 is illustrated in Figure 3 (see over).*

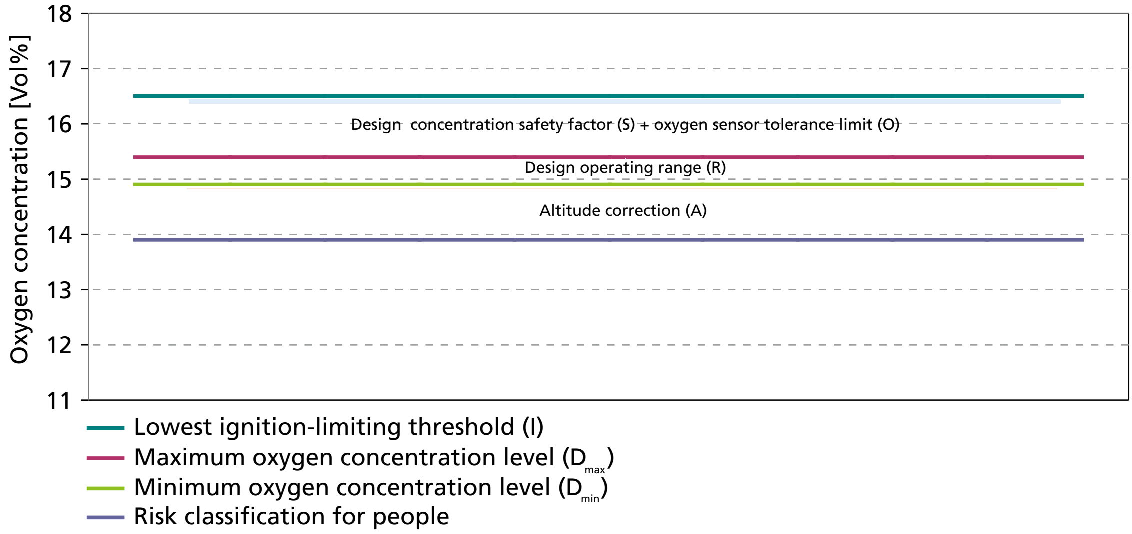
Table 1 – Classification of oxygen concentration levels (%) in protected spaces and associated minimum signage, alarms and access control measures (subject to the hazard and risk assessment)

Class	Oxygen concentration level at sea level (%)	Equivalent altitude (m)	Signage and alarms	Minimum access control measures
1	≥17.0	0 to 1,700 m	Signage at entry points Visual and audible low-oxygen alarm shall be triggered inside and outside the protected space should the oxygen concentration drop below 17.0%	Screening of personnel (including consideration of medical history/status and activity levels, where appropriate; see Annex C) Any other specific measures identified by the hazard and risk assessment
2	<17.0 to 15.0	>1,700 to 2,700 m	Signage at entry points Visual and audible low-oxygen alarm shall be triggered inside and outside the protected space should the oxygen concentration drop below 15.0%	Screening of personnel (including consideration of medical history/status and activity levels, where appropriate; see Annex C) Access control (e.g. keypad) Any other specific measures identified by the hazard and risk assessment for class 1, as above Any other specific measures identified by the hazard and risk assessment (e.g. automated cut-off, flushing or ventilation system)
3	<15.0	>2,700 m	Signage at entry points Alarm requirements to be identified by the hazard and risk assessment	Screening of personnel (including consideration of medical history/status and activity levels, where appropriate; see Annex C) Access control (e.g. keypad) Any other specific measures identified by the hazard and risk assessment for classes 1 and 2, as above Any other specific measures identified by the hazard and risk assessment (e.g. provision and use of breathing apparatus or temporary increases in oxygen level)

NOTE 1 *For class 3 systems, the local regulatory health and safety authority (e.g. HSE in the UK) should be consulted in conjunction with the hazard and risk assessment.*

NOTE 2 *For all classes of system, all signage should carry a general warning to the effect: "If in doubt, stay out."*

Figure 3 – System classification calculation from the design oxygen concentration level



NOTE Example as per figure 3:
Ignition-limiting oxygen threshold 16.5%.
Safety factor 1%.
Oxygen monitoring system tolerance 0.1%.
Maximum design oxygen concentration 15.4%.
Minimum design oxygen concentration 14.9%.
Altitude 410m (1% less oxygen by volume available for respiration purposes).
System classification should therefore be based on 13.9% available oxygen for respiratory purposes (i.e. class 3)

6.3 Visual and audible warnings

Appropriate warning and instructions signs shall be installed notifying persons of the presence of hypoxic air fire prevention systems and authorization requirements for accessing the area.

The following wording shall be adopted:

a) "You are entering a controlled environment with an oxygen concentration level of between *X*% and *Y*%. If you do not have the appropriate authorization, please report to [xxx]."

b) "If you feel shortness of breath or any other unusual symptoms, you should leave the environment immediately and inform your supervisor."

Visual and audible warning shall be provided at the door entrances and throughout the protected space.

6.4 Access control

Access control shall be provided for all spaces protected by hypoxic air fire prevention systems of class 2 or class 3. The access control for class 3 systems shall be as determined by the hazard and risk assessment but, as a minimum, shall be as for class 2 systems unless the hazard and risk assessment indicates otherwise.

The access control shall not prevent rapid exit from the protected space.

6.5 High oxygen levels

Where it is not possible to emit high-oxygen by-products straight to the atmosphere, this shall be at high level away from passage of people. In the immediate vicinity of the outlet, a warning sign shall be provided with the following text:

WARNING: High-oxygen gas outlet. Do not inhale. Do not deviate or obstruct the outlet.

Where it is not possible to emit high-oxygen by-products straight to the atmosphere, the high-oxygen by-product from the air separation unit shall not be discharged into a confined space such that the oxygen level exceeds 23.5%, and warning signs shall be provided with the following text:

WARNING: High oxygen level – do not enter without suitable breathing equipment.

A high oxygen level warning alarm, both visual and audible, shall be provided, set at an oxygen concentration of 23.5%.

6.6 Nitrogen injection systems

Provision shall be made to keep people in the fire-protected space at sufficient distance from nitrogen injection inlets to maintain health and safety.

7 Installation, testing and maintenance

7.1 Installation

The installation of hypoxic air fire prevention systems shall be undertaken by a competent person, comply with the system design specifications and include the following components:

a) air separation system (e.g. membrane, pressure swing adsorption);

b) the control panel, wiring and power supply;

c) an oxygen monitoring system;

d) the compressor and, where applicable, dryer;

NOTE A dedicated compressor/dryer system is recommended.

e) silencer system(s);

f) pipework (see **7.2**).

NOTE 1 The following are optional in the installation of hypoxic air fire prevention systems: wiring to the fire detection and alarm control panel, to the building management system control panel and to remote displays and indications; a water and oil separator; and pipework for clean water drainage.

NOTE 2 Electrical and mechanical equipment used in hypoxic air fire prevention systems may be subject to national legislation.

7.2 Pipework

Pipework shall include:

a) pipework for feeding hypoxic air from the air separation system into the protected space and for disposing of the high-oxygen by-product into the atmosphere;

b) non-combustible pipework for high-oxygen air.

NOTE Pipework types for high-oxygen air may include stainless steel, copper and flame-retardant plastic.

Upstream of the protected space, only ductile steel materials and non-ferrous metals shall be used.

NOTE In the protected space, plastic materials may be used; however, there should be no use of plastic materials that tend to embrittlement or are brittle already.

The nominal pressure level of mouldings and components to be installed shall be at least equal to the maximum anticipated design pressure. When dimensioning the pipework, the test pressure (at least 1.5 times the calculation pressure) shall be taken into account.

7.3 Testing

The completed system shall be reviewed and tested by a competent person in accordance with the specifications of the system designer and installer:

a) a full visual inspection of all system components shall be carried out to verify that the system has been installed in accordance with the design;

b) all open-ended pipework shall be pneumatically tested in a closed circuit for a period of 10 minutes at 3 bar. At 10 minutes, the pressure drop shall not exceed 20% of the test pressure;

c) system functionality shall be verified against the system specification. As a minimum, this shall include verification of design oxygen concentration level, limits of maximum and minimum oxygen concentration levels and alarm functionality;

d) all inputs and outputs of the system control panel shall be tested to confirm performance and functionality;

e) system performance in each protected space shall be verified by monitoring oxygen concentration level reduction over time from initial system start-up against design specification (see Figure 1);

f) the duty cycle of the air separation system shall be verified;

g) the hold time of each protected space shall be verified.

7.4 Documentation

Documentation shall be provided to the operator by the installer and shall include the following, as a minimum:

a) the system design specification (see **5.3**);

b) the installation hazard and risk assessment, together with notification of the legal responsibility of the operator or other dutyholder to undertake their own health and safety assessment;

c) a completion document containing the test results (see **7.3**) verifying the system design specification (see **5.3**), signed by the relevant competent person(s);

d) operation, maintenance and servicing instructions;

e) an installation report;

f) schematics showing the hypoxic air fire prevention system layout;

g) infiltration monitoring and testing procedures for the premises;

h) commissioning data;

i) manufacturer's declaration of conformity to BS EN 61508 and BS EN 54-4;

j) guarantee documentation;

k) equipment data sheets with manufacturer and installer contact details;

l) system logbook.

NOTE 1 All modifications should be documented and carried out by a competent person. After any modifications, a new system commissioning data report and an updated declaration of conformity should be issued and documented.

NOTE 2 Where required, documentation should be signed for and/or approved by the operator.

7.5 Operation, maintenance and servicing instructions

The operation, maintenance and servicing instructions shall include, as a minimum:

a) date of installation, details of the installer, and schematics and descriptions of the system operation and critical control functions;

b) protective measures identified through the hazard and risk assessment;

c) testing and maintenance procedures for all system components;

d) manufacturer's instructions for system servicing and testing (see Annex D);

e) contact details for warranty and technical support;

f) recommendations for alternative fire protection when the system is likely to be shut down or inoperable for periods that extend beyond the hold time of the protected space, including notifying insurance and fire authorities;

g) actions to be taken in the event of system fail alarm;

h) instructions to record system activity and servicing in the system logbook.

Annex A (informative)
Hypoxic air fire prevention system concept

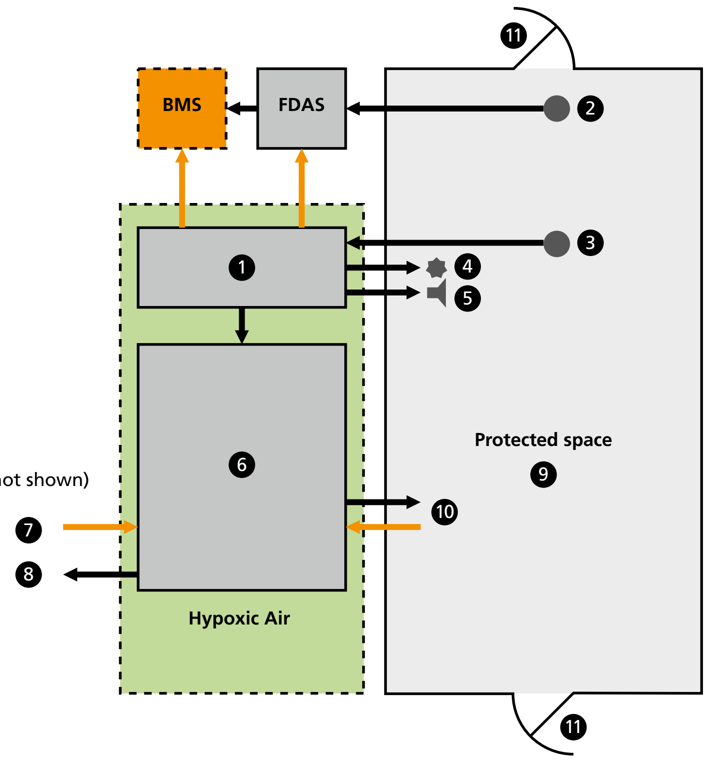
Normal (normoxic) air has an oxygen concentration level of 20.9% by volume. As altitude increases, the volumetric proportion remains constant but the actual number of oxygen molecules in any given volume reduces proportionally with decreased atmospheric pressure (hyperbaric atmosphere). As an example, in a commercial aircraft cabin space, the atmospheric pressure is 770 mbar, equivalent to 2,200 m altitude (at sea level, the atmospheric pressure is 1,013 mbar). The actual percentage of oxygen at this altitude remains at 20.9% by volume, but its partial pressure is equivalent to a sea-level oxygen concentration level of 15.8% by volume.

In a hypoxic air fire prevention system at sea level, the balance of the air is essentially made up of nitrogen molecules. Physiologically, the human body cannot tell the difference between higher altitude air and the reduced oxygen air produced by a hypoxic air system. The change in proportion of nitrogen with respect to oxygen stops flame propagation and provides a fire prevention medium. This is why a fire can occur in an aircraft but not in a correctly designed hypoxic environment.

For every 410–450 m above sea level, the available oxygen for respiratory purposes reduces by 1% by volume relative to that available at sea level.

Hypoxic environments can be established with either a hypoxic air generator system or a nitrogen injection system. Both systems create an environment with a reduced oxygen level but differ in the oxygen concentration of the airflow introduced into the area by the system. A generic arrangement is shown in Figure A.1.

Figure A.1 – Hypoxic air fire prevention system concept



1 Control panel and power supply
2 Smoke detection
3 Oxygen monitoring (minimum of two sensors)
4 Visable alarm (strobe light)
5 Audible alarm
6 Air separation system
7 Ambient air (optional)
8 Oxygen-enriched air out
9 Hypoxic air
10 Air exchange (ambient air ventilation and infiltration not shown)
11 Access

FDAS Fire detection and alarm system
BMS (optional) Building management system

Both systems are recognized as efficient methods of creating continuous hypoxic air environments for fire prevention. Once established, the oxygen concentration is monitored and supervised constantly.

Hypoxic air fire prevention systems need a finite time to generate the hypoxic atmosphere. Hypoxic atmospheres are created over a period of many hours by replacing the contents of the ambient air. The molecular weight is not sufficiently different to prevent a homogeneous atmosphere from forming throughout the protected space, and differences in oxygen concentration at high/low level are not observed.

Should such systems be deactivated for servicing or because of critical operation failure, the fire-preventing atmosphere remains in place for a period of time, called the hold time. In larger protected volumes, the hold time may be many hours, or a day or more, which may allow time for repair or for provisional measures to be established so protection can remain uninterrupted. However, taken in isolation, a hypoxic air generator has components that can potentially fail. If that compromises risk protection, then means of addressing this through redundancy of active components should be considered.

Annex B (normative) Ignition-limiting oxygen threshold testing

B.1 Principle

Solid materials shall be heated with a flame in a hypoxic air fire-preventative environment to assess the ignition-limiting oxygen threshold.

NOTE The test method in VdS 3527:1997, Annex A5.2, may be used as an alternative to this test and should be used for testing liquids.

B.2 Test facility

B.2.1 The test facility shall consist of a 100 m^3 space built to BS EN 15004-1 specifications fitted with an air separation system and an air lock in front of the entrance (see **B.2.4**).

The height of the space shall be at least 2.2 m.

All penetrations by test set-up equipment, pipework, measurement cables and sensors shall be sealed with non-combustible foam sealants.

There shall be no significant draft in the room, and control of the flame torch shall be remote with no access to the space during the test.

NOTE 1 Under these conditions, this test may be performed in situ at much larger volumes as well, to account for large components in storage or special arrangements.

*NOTE 2 Alternatively, spaces with volumes no less than 10 m^3 may be used provided the oxygen concentration level, measured as the mean reading of the two lowermost oxygen sensors (see **B.5.2**), is within a deviation of ±0.1% by volume during the test.*

NOTE 3 The air separation system may be a standard equipment set-up at the testing facility, or it may be a proprietary system that the user is assessing under standardized testing conditions.

B.2.2 The test facility shall be fitted with smoke extractor fans.

B.2.3 The test facility shall be fitted with opposing observation windows to allow observation of the fire test.

B.2.4 The test facility shall be equipped with an adjoining air lock vestibule of equal height and minimum 2.5 m width x 1 m length to limit air infiltration.

The test facility shall be equipped with doors and observation windows that are sealed with smoke sealant.

B.3 Test sample and specimens

The test sample shall be a batch of identical test specimens.

NOTE The following materials are not suitable as test specimens: explosive mixtures of gases, particulates and liquids; reactive metals, cellulose nitrate, gunpowder, metal hydrides, hydrazine and other chemicals capable of autothermal decomposition.

For any protected space, the applicable test sample shall be that with the lowest ignition threshold that may reasonably be expected to be located within it.

B.4 Apparatus

The apparatus shall consist of the following items (see Figure B.1).

B.4.1 An oxyacetylene torch, with the ability to provide flaming exposure, regardless of the oxygen concentration level or other room climate conditions.

B.4.2 Three oxygen sensors, positioned within the test facility at heights of 0.2 m, 1.2 m and 2.2 m in a vertical line, at least 1 m away from the test specimen on the opposite side to the torch.

B.4.3 A calibrated scale to measure specimen loss of mass.

B.4.4 Thermocouples, installed inside the room to measure temperatures.

B.4.5 Data-logging equipment, installed to record readings throughout the test.

B.4.6 Video-recording equipment.

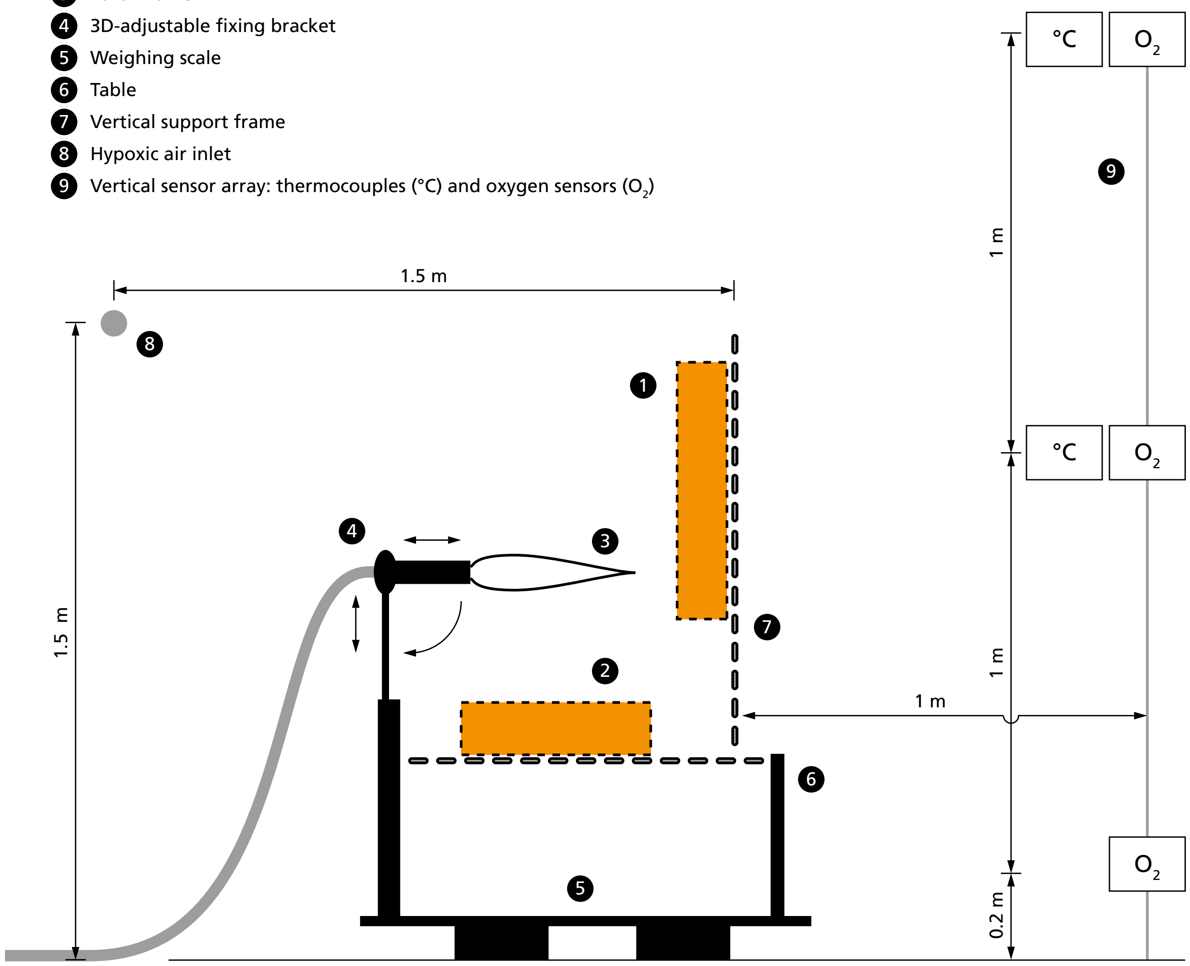
B.4.7 A heavy-gauge steel wire mesh frame, installed inside the room to support vertical samples.

B.4.8 A heavy-gauge metal-frame table with wire mesh, installed inside the room to support horizontal specimens.

B.4.9 A heavy-gauge metal bracket to support the torch and its remote operation.

Figure B.1 – Ignition-limiting oxygen threshold testing set-up

1. Vertical test specimen
2. Horizontal test specimen
3. Torch flame
4. 3D-adjustable fixing bracket
5. Weighing scale
6. Table
7. Vertical support frame
8. Hypoxic air inlet
9. Vertical sensor array: thermocouples (°C) and oxygen sensors (O_2)



B.5 Test procedure

B.5.1 Set the video-recording equipment (**B.4.6**) to record each test for review after completion.

NOTE A review may be necessary for closer inspection after the test to establish whether there is smoking or not.

B.5.2 Place the specimen on the metal-frame table (**B.4.8**), fixed in a horizontal position.

B.5.3 Fix the oxyacetylene torch (**B.4.1**) on the bracket (**B.4.9**) such that the flame will hit a lateral side of the test specimen. Fix the flame nozzle at an angle of 90 degrees towards the specimen, with the flame outlet spaced 0.2 m away from it and approximately 0.025 m inwards from the edge of the specimen.

B.5.4 Record the oxygen concentration levels of the oxygen sensors (**B.4.2**) using the data-logging equipment (**B.4.5**).

B.5.5 Fill the test facility with hypoxic air so that the oxygen concentration level is at the desired value.

B.5.6 Set the unobstructed length of the torch flame to 0.3 m. Subject the test specimen to a flame set at the transition point from orange to blue flame colour for 180 seconds.

B.5.7 Observe whether the test specimen ignites.

B.5.8 Measure the loss of mass to the specimen during the test using the calibrated scale (**B.4.3**). Record the specimen mass before the start of the test and 180 seconds after removing the torch flame (post-exposure time). Observe the specimen for a further 60 seconds to see whether it continues to produce flames independently of the torch, and then record its mass again.

NOTE It may be useful to produce a graph to chart mass loss throughout the test.

B.5.9 Fix a new specimen from the same batch in the vertical position on the metal frame (**B.4.7**).

B.5.10 Repeat provision **B.5.3**, but with the flame pointing towards a lowermost corner of the vertical specimen.

B.5.11 Repeat provisions **B.5.4** to **B.5.8**.

B.5.12 Repeat the tests at least twice more for each sample, each time with the oxygen concentration level being increased by 0.5% by volume, or as agreed otherwise, until the ignition-limiting oxygen threshold is established.

B.5.13 Exchange the air inside the test room before carrying out the test with horizontal configuration and before carrying out the test with vertical configuration, to keep conditions consistent (room temperature at 20°C, and no air pressure differential to the outside).

B.5.14 For each type of specimen and configuration, perform a reference test to determine ignition and burning properties in normobaric normoxic conditions.

NOTE Local health and safety and environmental regulations for handling hazardous materials should be consulted.

B.6 Test documentation

B.6.1 The following shall be recorded prior to the test:

a) spacing of specimens (if multiple specimens are tested);
b) torch location, flame colour, angle towards and distance from specimen;
c) material:
    - mass (kg);
    - dimensions (m);
    - type and shape;
    - packaging (if any);
d) system:
    - type of hypoxic air supply;
    - date of manufacture;
    - manufacturer name;
    - capacity of the air separation system and oxygen concentration level (% by volume);
    - for nitrogen gas injection hypoxic air systems, capacity in terms of nitrogen airflow and nitrogen concentration level (% by volume).

B.6.2 The following shall be recorded during each test:

- time of exposure (seconds) of the test specimen to the flame;
- ignition time (seconds) after exposure to the flame;
- mass loss (grams) during flame exposure and during the post-exposure observation period;
- oxygen concentration level (% by volume) in the room throughout the test;
- observation of any smoke generation throughout the test;
- observation of sustained flaming (duration in seconds) after removal of the flame;
- temperatures in the room (°C).

B.7 Test criteria

B.7.1 The measured ignition-limiting oxygen threshold shall be recorded when tests of identical specimens tested both horizontally and vertically have passed the following criteria:

e) no self-sustained burning or spread of fire observed on the specimens beyond the area directly hit by the torch flame during 180 seconds of exposure to the flame;

f) no self-sustained burning or spread of fire observed on the specimen for a duration of 60 seconds after removal of the burner flame.

When tests of two specimens show that one orientation has a lower ignition-limiting oxygen threshold, only that orientation shall be used for further testing (see **B.5.12**).

B.7.2 Pure, mixed or encapsulated specimens that are subject to glow, rekindle or smoulder by oxidation shall be tested by the procedure given in **B.5**. An extended period of observation during the post-exposure time shall then apply, the length of which shall be set by the laboratory.

Annex C (informative)
Health and safety: working in hypoxic environments

C.1 General

Hypoxic air fire prevention systems prevent fires from occurring by changing the proportions of oxygen and nitrogen in the air. Fire is sensitive to this relationship, whereas human physiology is sensitive only to any change in absolute availability of oxygen, irrespective of whether this occurs as a result of a change in barometric pressure or as a result of manipulation of the air composition, as occurs in hypoxic fire prevention. As a result, hypoxic air fire prevention systems may be considered to be analogous in risk to naturally occurring altitude environments with the same partial pressure of oxygen.

There are three physiological factors that define the risk, if any, posed by hypoxic environments to healthy persons occupying them:

a) oxygen partial pressure;

b) duration of exposure;

c) the level of exertion required to carry out any task.

An additional and important external factor is whether the person is able to leave the protected space at any time or not. It would in most instances be relatively simple to leave a hypoxic environment associated with a protected space, compared with leaving an aircraft in flight, where the oxygen availability is typically equivalent to a hypoxic air environment of 14.5% to 15.5% at sea level.

A guide to the equivalent altitude to the oxygen levels created by hypoxic air fire prevention systems is given in Table C.1. Some locations that experience the same oxygen partial pressures are also listed.

C.2 Pre-existing medical conditions

People with pre-existing heart or lung conditions may have an increased risk compared with healthy persons under the same conditions. This does not automatically exclude these persons from work in hypoxic environments, but medical advice should be sought [1].

C.3 Health and safety assessment

C.3.1 Sample questionnaire for persons likely to enter a class 2 or class 3 hypoxic environment

a) Do you have any known heart disease?

b) Do you have any known lung or airway disease?

c) Do you have anaemia?

d) Do you have, or have a family history of, inherited blood disease, low blood count, anaemia or sickle-cell anaemia?

e) Have you ever experienced any pains (with the exception of headaches), such as abdominal, chest or joint pains, nausea, vomiting, shortness of breath or fatigue during previous stays at high altitude (mountains) or during aircraft flights?

f) Have you ever had a stroke or a mini-stroke (transient ischaemic attack)?

g) Have you ever been treated for rhythm problems of the heart?

h) Have you had any episodes of dizziness within the last 3 months that have prevented you from pursuing your normal daily activities?

Table C1 – Oxygen partial pressure and concentration level for given altitudes with example locations

Altitude (m)	Oxygen partial pressure (mmHg)	Oxygen concentration level (% by volume at sea level)	Location
0	158.8	20.9%	London
1000	141.8	18.5%	Oberwiesenthal, Germany. Bangalore, India
2000	123.6	16.4%	Obergurgl, Austria. Saint Véran, France
3000	110.4	14.3%	Pistes at Cortina, Italy
4000	96.4	12.7%	Pistes at Chamonix, Courcheval and Les Arces, France
5000	84.2	11.1%	Wenzhuan, China (highest city in the world)
6000	73.7	9.7%	Kilimanjaro (peak)

i) Do you have to pause during your daily activities at work or at home because of shortness of breath?

j) Have you experienced any chest pain within the past 3 months while at rest, or while under physical or mental stress?

k) Have you woken up in the past 3 months because of shortness of breath?

l) If female, are you currently pregnant?

m) Are there any known medical issues that you think might affect you working in a low-oxygen environment? If so, please specify.

n) Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

If the person responds with "YES" to any of the above statements, they should be referred to a qualified physician to determine whether they should be allowed to enter the hypoxic environment and, if so, under what limitations (if any).

Annex D (normative) Servicing

Instructions for the servicing of the system shall be provided by the installer in the manufacturer's operations and maintenance manual provided to the operator or other dutyholder at handover. The servicing instructions shall require that main system elements undergo periodic inspection at regular intervals, including as a minimum:

a) daily, system control panel status;

b) weekly, compressor check;

c) at regular intervals appropriate to usage but at least every 3 months, air locks and other critical infiltration points.

NOTE *Pressure vessels should be inspected and tested in accordance with the regulations applying in the country of operation*

The servicing instructions shall require verification of the system to include:

a) daily, oxygen levels and all alarm status indicators;

b) weekly, compressor system status;

c) every 3 months, oxygen sensors and the oxygen monitoring system. They shall be compared with a separate calibrated device;

d) every 3 months, low- and high-oxygen alarms and any associated beacon/sounder devices;

e) every 6 months (or more frequently, as determined by operational hours and the requirements of the compressor manufacturer):
   - pipework. Pipework showing corrosion or mechanical damage shall be pressure tested and repaired or replaced as necessary;
   - all valves for correct function;
   - defined-service-life components (e.g. filters) in the compressor system and hypoxic air generator. They shall be replaced as necessary;
   - the duty cycle.

The servicing instructions shall require all servicing actions to be recorded in the system logbook.

NOTE *An increase in the duty cycle would indicate a reduction in system performance or increased infiltration in the protected spaces. Infiltration may have increased because of more access events into and out of the protected spaces, or the area of infiltration may have increased. Work should be carried out to reduce the infiltration (which may include revised access controls) to restore system performance.*

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BSI
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