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Fire Performance of Green Roofs and Walls

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Contents

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The views expressed in this report are those of the authors and do not necessarily represent the views or proposed policies of the Department for Communities and Local Government.

1 Introduction

Green roofs have been used in construction for many years, most notably in Germany, Switzerland and Austria, where the industry began in the 1960s. There is now considerable and increasing interest in establishing green roofs in the UK. Green walls, in the form of climbing plants, have also been established for centuries, however there have been a number of new products entering the market recently, which provide support for a wider range of plants.

This document will serve to provide a review of the current guidance documents available and to illustrate the results of testing which has been carried out on green roofs and green wall systems. This document will also provide guidance on the fire performance aspects of green roof and wall construction and maintenance.

1.1 Green roofs

There are generally three types of green roof systems, extensive, semi-intensive and intensive, which are comprised of a number of layers, as illustrated in Figure 1.

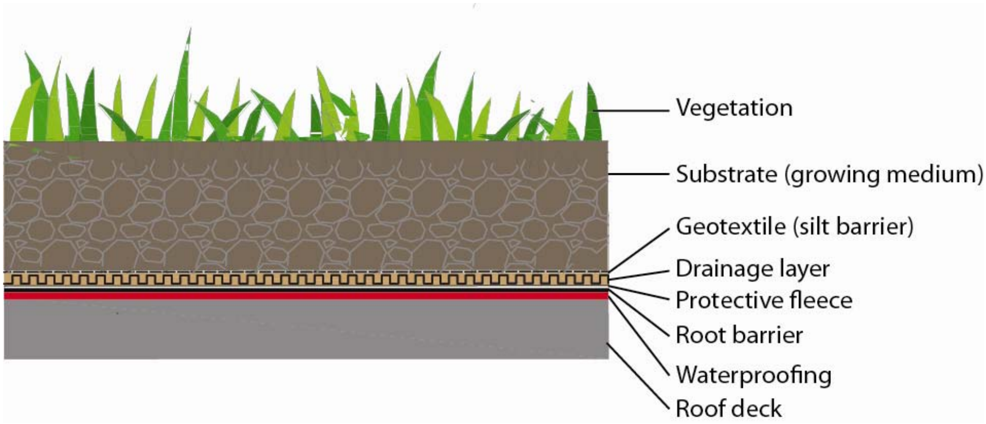


Figure 1. Typical build up of a green roof system (courtesy of Green Roof Consultancy)

An extensive roof is a lightweight, low maintenance roof system typically with low growing ground cover, eg mosses, herbaceous plants, succulents and other hardy plant species planted in a shallow substrate. The depth of the growing medium is typically between 80 and 150mm on a well designed system. The organic content of the growing layer is usually less than 20%. Generally this type of roof does not normally require irrigation and is low in nutrients, however Factory Mutual guidance recommends the provision of rooftop hose-bibs to allow irrigation in drought periods. An example of an extensive roof is shown in Figure 2.

Figure 2. Typical extensive green roof (courtesy of Green Roof Consultancy)

The GRO Green Roof Code also makes reference to a Biodiverse roof which is similar in composition to an extensive roof but designed to create a habitat which will attract specific flora and fauna.

A semi-intensive roof is an intermediate green roof type with characteristics of both extensive and intensive roofs. They tend to have a wider range of plants including shrubs and woody plants compared to extensive roofs. In general the depth of the substrate is between 100mm and 200mm. The guidance varies with regard to the requirements for irrigation and maintenance; the GRO Green Roof Code guidance states that irrigation and maintenance requirements are dependent upon the plant species installed, whereas the Factory Mutual datasheet 1-35 recommends a permanent irrigation system for this type of roof.

Intensive roofs are often referred to as a roof garden as the vegetation can consist of a variety of plant types, such as ground cover, herbaceous plants, grasses, woody shrubs and small trees. This type of roof requires regular maintenance and irrigation and the depth of the growth media is generally greater than 200mm. Factory Mutual datasheet 1-35 recommends a permanent irrigation system for this type of roof. An example of an intensive roof is shown in Figure 3.

Figure 3. Typical intensive green roof (courtesy of Green Roof Consultancy)

1.2 Green walls

Green walls using climbing plants are an ancient technique. Green walls (sometimes referred to as living walls) are deliberately vegetated facades and there are less established guidelines on their use. Broadly speaking the effect is achieved in a number of ways as follows:

- climbing plants growing directly against the wall or trained against a trellis - A trellis of steel wires or mesh is used as a support for climbing plants, which can be rooted into the ground or substrate-filled planters, which can be supported at height if required. Such systems are usually irrigated but can survive without irrigation if rooted into the ground

- hydroponic green walls - These systems are usually constructed from plastic mesh, geotextiles, fabrics or horticultural mineral wool or combinations of materials fixed to supporting frames or boards. Plants grow without substrate or soil and rely of irrigation and nutrients added to irrigation water

- modular green walls - Usually manufactured from purpose made HDPE modules containing cells which are filled with growing medium and planted. Modules are fixed to a wall or frame and may be combined to cover large areas.

Irrigation water is usually delivered to the top of each module via irrigation lines. Nutrients can be contained in soil or added to the irrigation supply. Figure 4 shows a living wall at Tower Gateway, London and Figure 5 shows a living wall in Paris.

Figure 4. Living wall installation at Tower Gateway (courtesy of Gary Grant)

Figure 5. Living wall installation, Paris (courtesy of Gary Grant)

1.3 Features of green roofs and walls

Also known as "living roofs", green roofs can provide a number of benefits for a building, such as:

- adapting to climate change – living roofs can counter the urban heat island effect by increasing albedo and providing evaporative cooling
- pollution abatement – green roofs can reduce air pollution levels by trapping particulates and capturing gases
- sustainable drainage – living roofs can reduce the risk of flooding by reducing the amounts of storm water run-off. This also results in lower burdens on the sewer networks
- sound attenuation – the additional mass of the living roof can provide sound attenuation
- biodiversity – urban developments can lead to a reduction in habitat however this can be recreated by living roofs which actively encourage flora and fauna into the area. Indeed many areas can support interesting and rare species
- amenity value – denser and more compact areas lead to a reduction in garden space, therefore green roofs can benefit the building occupants by providing necessary outdoor recreational areas and outdoor living space
- financial – installing a living roof can extend the life of the roof covering by reducing the thermal stresses induced by UV rays. In addition the insulation provided by the green roof lowers the energy consumption and hence the energy costs for the building.

It has been suggested that green roofs and walls may constitute a fire hazard. In relation to fire performance, the general consensus is that as long as the green roof or wall is kept moist (which is the normal case in order to keep the roof alive) it is likely to be very resistant to ignition.

However concern has been raised that if the green roof or wall dries out (such as might happen in a drought if no irrigation is provided) then they might present more of a fire risk. There has historically been a limited amount of fire testing of green roofs (carried out in Germany) but this does not necessarily address all the potential concerns. The other factor is that there is no significant fire testing of green wall systems.

In order for additional requirements to be introduced for green roofs or walls, it would need to be demonstrated that there is a reasonable probability that they could ignite and that the fire could spread in such a way that it would cause a breach of the functional requirements of the Building Regulations.

2 Synopsis of current guidance

The current guidance available for review is mainly from the United States and from mainland Europe. There are some guidance documents available in the UK however these are generally based on the German guidance produced by the FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftbau (Landscape Research, Development and Construction Society)).

The following documentation has been reviewed as part of this project:

- Factory Mutual Global Property Loss Prevention Data Sheets 1-35 – Green Roof Systems (2007)
- ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs
- The GRO Green Roof Code (2011).

The above documentation has been reviewed with respect to fire safety of green roofs. Where design issues do not specifically involve a fire safety risk but may do so indirectly, as may be the case for wind load design, this has been included in the review. Otherwise, the documentation will be commented on only in respect of specific fire safety concerns.

2.1 Slope of roof

In practice there are many green roof systems with zero falls and green roofs can be created on any slope. However the guidance generally gives a minimum and maximum slope for green roofs. FM datasheet 1-35 states that green roofs supported by structural concrete decks should have a minimum slope of 2% (1.1°), and green roofs supported by other structural systems (eg metal roof deck) should have a minimum slope of 3% (1.8°).

Roof slopes greater than 20% (11°) should be provided with additional anti-shear stability layers and erosion control, and roof slopes greater than 40% (22°) are not recommended due to stability and erosion problems.

The GRO Green Roof Code recommends anti-shear measures for roof pitches in excess of 20° however the 2008 version of the German FLL standard recommends these measures for roofs with slopes greater than 15°.

The ANSI/SPRI guidance is limited to roof slope designs up to 2 in 12 (16.7% or 9.5°).

2.2 Wind design

Each document recognises that wind design is the first governing criteria when determining if a green roof should be considered for a building. Fire safety design should follow subsequent to this approval.

The FM datasheet 1-35 states that green roof systems should only be installed in geographical locations where the basic wind speed (3 second gust), as determined from FM datasheet 1-28 Design Wind Loads, does not exceed 100mph (45m/s). Figure 18 of FM datasheet 1-28 gives the basic wind speeds in miles per hour for Europe, and for the majority of countries (with the exception of the far west of Ireland and north and west Scotland) the wind speed is less than 45m/s.

The European guidance makes less reference to the wind speed but does state that green roof designs should comply with all relevant structural design criteria. In addition where green roof elements are being used as ballast to prevent items that are not mechanically fixed from wind uplift, sufficient weight must be incorporated into the green roof build up and dry weights must be used to calculate the weight of the green roof system. Traditional “Nordic” style pitched green roofs frequently occur in locations which have high winds however the green roofs are used to weigh down the waterproofing layer. This practice is contradictory to the advice in the FM datasheet however the European guidance allows for this.

2.3 Prevention of fire

The guidance reviewed generally states that green roofs should be designed to provide the necessary resistance to the external spread of fire by the following measures:

- increasing the non-combustible content of the growing medium
- decreasing the organic content of the growing medium
- preventing the system from drying out.

Extensive roofs are not generally irrigated therefore the fire risk is mitigated by the specification of the build up and fire breaks, and by reducing the organic content.

GRO Green Roof Code states that the substrate depth should be greater than 30mm and the organic content should not exceed 20%. Succulent plants are also recommended as these retain water within their structure and thus reduce the risk of the substrate drying out.

The ANSI guidance also refers to fire resistive vegetative systems as “succulent based” and “grass based” systems and in both cases the growing media must contain at least 80% inorganic matter. The non-vegetative portions of the roofs must be systems that are classified ASTM E108 Class A.

FM datasheet 1-35 does not specify any limits on the organic content of the growing media but recommends that plantings should be limited so that the full-grown height of the vegetation will not exceed 0.9m. The use of grasses and mosses should also be avoided, instead fire-resistant plants should be used, eg those with a high moisture/low resin content as exhibited by plants with supple leaves and watery sap.

Where intensive roofs are concerned, the German FLL guidance and the GRO Green Roof Code have designated “intensive greening which is irrigated, regularly maintained and has a thick substrate layer” as a “hard roof”, and therefore it has no greater fire risk than a conventional roof finish.

Provision of fire breaks

A number of guidance documents reviewed refer to the provision of non-vegetated border zones or fire breaks in specific areas such as around all openings in roofs, around vertical elements, and at intervals across roofs to limit the area of the green roof. The fire breaks typically consist of non-vegetated strips, made of ballast with a nominal diameter of 20-50mm, or concrete paving stones.

The use of non-vegetated border zones is recommended for the following reasons:

1. to provide maintenance access, especially for green roofs consisting of vegetation which is not intended to support foot traffic;
2. to provide resistance to wind uplift pressures and to reduce scour of growth media;
3. to reduce the generation of wind-borne debris at roof perimeters; and
4. to provide a fire break at equipment, structures and penetrations located on the roof.

In the FLL Guidelines and the GRO Green Roof Code the general requirement is that fire breaks 500mm wide should be installed around all openings of the roof and vertical elements. Where the walls have sills an 800mm wide strip is required and fire breaks with a width of 1m should be installed at 40m intervals across the roof. End walls, fire walls and separating walls must extend above the substrate by a minimum of 300mm with a maximum distance of 40m between such walls (extensive roof systems). If the end walls, fire walls and separating walls do not extend above the substrate then a 300mm high non-combustible top piece or a strip made of concrete slabs/gravel will be considered acceptable.

The ANSI/SPRI guidance states that fire breaks should be Class A (as per ASTM E108 or UL 790) rated roofing systems for a minimum 1.8m wide continuous border. Individual green roof sections are limited to 1450m^2 with a maximum dimension of 39m and they must be divided by fire stop walls of non-combustible construction which extend above the roof surface by a minimum of 914mm, and a 1.8m wide fire break border.

FM Datasheet 1-35 recommends the provision of a continuous 500mm wide border around all roof top equipment and penetrations, skylights, solar panels, antenna supports, expansion joints, roof area dividers, and interior parapet walls. If the interior parapet wall is a Maximum Foreseeable Loss (MFL) fire wall then vegetation free borders covered with stone or concrete ballast should be installed to extend a minimum of 15m on each side of the MFL wall.

The guidance also recommends a continuous border of 0.9m around all rooftop structures, including but not limited to mechanical and machine rooms, penthouses, and adjacent façade walls.

The area and maximum dimension of the green roof sections is limited in the same way as the ANSI guidance, with the divisions made by fire stop walls with a border of minimum width 0.9m.

If the roofing membrane relies on ballast to resist wind uplift pressures then a continuous border of 2.6m for the roof perimeter and corner areas applies. If ballast is not used then the guidance in FM datasheet 1-28 should be used to define the perimeter and corner border requirements. Roof gravel or stone ballast should not be used for green roof systems on buildings over 46m high, instead concrete pavers should be used.

FM Datasheet 1-35 recommends that perimeter parapet walls should be provided for all green roof systems, which should extend a minimum of 150mm in elevation above the top of the growth media, stone ballast or concrete pavers. Where roof elevations are above 46m the perimeter parapet walls should be a minimum of 760mm in height, and where parapet walls of this height are provided the adjacent border zones (which should be free of vegetation and growing media) may be reduced to a minimum of 0.9m.

Provision of fire hydrants

The ANSI/SPRI VF-1 guidance is the only document to specifically state in the system requirements and general design considerations that access to one or more fire hydrants should be provided.

2.4 Green roofs at grade level

The FM datasheet 1-35 also recognises that green roofs at or below grade level, ie the level at which the ground surface meets the foundation of a building, will require some design consideration in order to ensure that vehicular access is restricted or else the roof must be designed to take such loads. In addition the guidance specifies that a continuous vegetation-free border should be applied to such at-grade roofs with a minimum width of 0.9m to reduce the risk of fire spread to or from the roof. This provision may be modified by FM datasheet 9-19 Bushfire Exposure if the surrounding vegetation is considered to be a particular fire hazard. Likewise, other similar potential fire hazards in close proximity to a green roof should be evaluated on a site-specific basis. Minimum roof slopes for drainage are recommended depending upon the deck material with additional shear anchorage required for roof slopes between 11 and 22°.

2.5 Other guidance

In addition to the above guidance a number of other documents form part of this review of the available literature.

"Bridging The Gap – Fire Safety and Green Buildings" is a document which presents a wide-ranging narrative study of various green building techniques and their impact on fire service operations, produced by the National Association of State Fire Marshalls in the United States. Vegetative roofs are included within this assessment and in general the document defers to the FM Global Loss Prevention Datasheet 1-35 on specific criteria. The document is in essence a commentary on the FM datasheet guidance given from the perspective of the United States fire service. Within this document the US fire service raise concerns about the following issues:

- the ability of the growth media and vegetation to remain in place, including during high winds, in order to protect fire service personnel and equipment, however this could be applied to the public at large
- the provision of a clear space around the roof perimeter for the use of fire fighters (and of a width commensurate to this use) without giving specific dimensional details
- the installation of parapets, ostensibly for the purpose of preventing growth media sliding off the roof onto people below during extended adverse weather events.

However if the guidance in FM datasheet 1-35 is followed then the above issues will be resolved since there are guidelines relating to the whole roof assembly which cover the permissible wind speeds where green roofs can be located and the loads which must be allowed for. The FM guidance also specifies that perimeter parapet walls should be provided for all green roof systems.

Notwithstanding the above the United States fire service recommends that the minimum roof slope should be 2-3% for efficient drainage in the “Bridging The Gap” report. The report however does not state where these figures are derived from and they are slightly in excess of the FM guidance. It should also be noted that in practice many green roofs have zero falls and the slope is not related to fire risk. It is also recommended that the roof be designed to support loads associated with a fully saturated green roof, with a safety factor built in should future changes to the roof configuration be envisaged. The installation of plants containing high levels of volatile oils or resins should be avoided on green roofs given the increased fire loading such vegetation represents.

The FM Approval Standard for Vegetative Roof Systems Class Number 4477 is a standard which states Approval requirements for vegetative roof systems that are used within an FM Approved roof assembly, and it is applicable to all vegetative roof systems that are installed over an FM Approved roof assembly system, in this case a single-ply, polymer-modified bitumen sheet, built-up roof or liquid applied roof cover assembly. The document is not intended to determine suitability for the end use of a product but is rather “…*to evaluate only those hazards investigated*”.

Two testing regimes are relevant; the first assesses the combustibility above the roof deck to ASTM E 108, and the second assesses the combustibility below the roof deck using the FM calorimeter test procedure. The combustibility above deck of a roof system may be defined according to the test performance as either Class A, B or C, of which Class A exhibits the lowest flame spread (less than 1.83m). The Class A rating is the basis for the adoption of the 1.8m fire breaks in the ANSI/SPRI VF-1 guidance, thus implying that this standard requires green roofs to achieve a Class A standard. The FM Approvals documentation implies in its disclaimer of end use suitability, that roof systems should achieve at least a Class C rating to be considered acceptable in addition to fulfilling other criteria such as minimising lateral flames and minimising spread of glowing embers/debris from the roof such that none such continue to glow after reaching the floor.

3 Risks of green roofs/walls in relation to building regulations requirements

The main factors to be considered in terms of fire risk would be:

- how hard it is to ignite the organic material?
- what is the likelihood and speed of fire spread through the organic material?
- what is the likelihood, speed and consequences of fire spread back into the building?

In order to provide this guidance document testing has been carried out to determine whether there is a reasonable probability that the green roofs and walls could ignite and that the fire could spread in such a way that it would cause a breach of the functional requirements of the Building Regulations. The functional requirements relate to five different areas:

- B1 – Means of warning and escape
- B2 – Internal fire spread (linings)
- B3 – Internal fire spread (structure)
- B4 – External fire spread
- B5 – Access and facilities for the fire service

When considering the risks associated with green roofs and walls their use could potentially affect B2, B3, B4 and B5. At this time there do not appear to be any significant issues identified with green roofs/walls in relation to means of escape *per se*.

When considering the internal fire spread (linings) there may be potential for flames to spread through a green roof deck into a building and vice versa.

When considering the internal fire spread (structure) there may be potential for fire spread over a compartment wall or across a roof into a compartment (stepped façade). There may also be potential for fire spread across a wall façade which could compromise compartmentation, or a detachment of the wall façade may occur.

When considering the external fire spread there may be a risk of ignition of, or ignition by, an adjacent building by radiant heat and/or burning embers.

When considering access and facilities for the fire and rescue service there may be a risk that fire spread across a wall façade could be extensive and difficult to fight.

4 Building regulations requirements

4.1 Requirement B2

1. *To inhibit the spread of fire within the building, the internal linings shall:*

   a) *adequately resist the spread of flame over their surfaces; and*

   b) *have, if ignited, a rate of heat release or a rate of fire growth, which is reasonable in the circumstances.*

Internal linings mean the materials or products used in any lining partition, wall, ceiling or other internal structure.

In order to comply with Regulation B2 the walls and ceilings should meet the classifications outlined in Table 10 of Approved Document B, reproduced below.

Table 10 **Classification of linings**

Location	**National class** (1)	**European class** (1)(3)(4)
Small rooms (2) of area not more than: a. $4m^2$ in residential accommodation b. $30m^2$ in non-residential accommodation	3	D-s3, d2
Other rooms (2) (including garages)	1	C-s3, d2
Circulation spaces within dwellings		
Other circulation spaces, including the common areas of blocks of flats	0	B-s3, d2

4.2 Requirement B3

1. *A wall common to two or more buildings shall be designed and constructed so that it adequately resists the spread of fire between those buildings.*

2. *Where reasonably necessary to inhibit the spread of fire within a building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following:*

   a) *sub-division of the building with fire resisting construction;*

b) installation of suitable automatic fire suppression systems.

With regard to Regulation B3, and in relation to the junction of compartment walls with roofs, there are three fundamental recommendations:

1. compartment walls must be taken up to meet the underside of the roof covering or deck and fire stopping should be provided where necessary at the junction of the wall and roof to maintain the compartmentation

2. where a compartment wall meets a roof, the zone of the roof 1500mm wide on either side of the wall should have a covering designation AA, AB or AC on a substrate or deck of a material of limited combustibility

3. as an alternative to providing the protected zone the compartment wall may be continued up through the roof for a height of at least 375mm above the top surface of the adjacent roof covering.

With regard to Item 2, where buildings are used for Residential (not Institutional), Office and Assembly and Recreation purpose groups, with a height less than 15m, combustible boarding used as a substrate to the roof covering, wood wool slabs, or timber tiling battens, may be carried over the compartment wall provided that they are fully bedded in mortar or other suitable material over the width of the wall.

Note: Double skinned insulated roof sheeting, with a thermoplastic core, should incorporate a band of material of limited combustibility at least 300mm wide centred over the wall.

The above provisions are illustrated in Diagram 30 of Approved Document B, reproduced below.

It should also be noted that where a roof performs the function of a floor then it is considered to be an element of structure and should be provided with the appropriate fire resistance, as determined from Table A2 in Approved Document B in relation to the height of the building. This is more relevant for a semi-intensive roof or an intensive roof which is likely to be used as an amenity space.

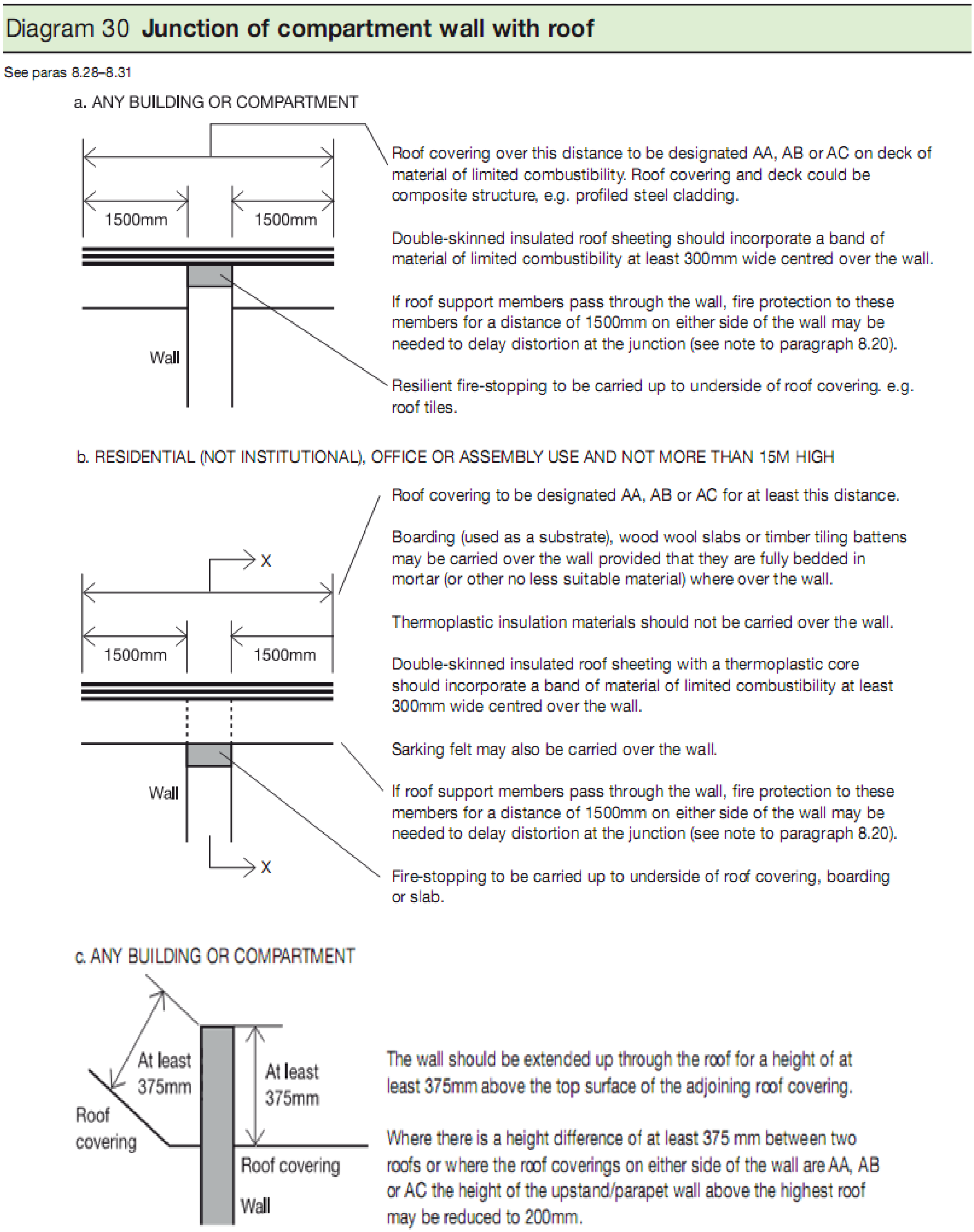


Figure 1. Diagram 30 in Approved Document B

4.3 Requirement B4

1. The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building.

2. The roof of the building shall adequately resist the spread of fire over the roof and from one building to another, having regard to the use and position of the building.

The guidance in Approved Document B limits the use of roof coverings near a boundary which will not give adequate protection against the spread of fire over them. The term roof covering does not refer to the roof structure as a whole, but is used to describe constructions which may consist of one or more layers of material. The recommendations in Section B4 of ADB refer to the performance of roofs when exposed to fire from the outside.

Roof coverings are given a designated rating based on their performance in BS 476-3: 2004 or BS EN 13501-5: 2005, and examples of common roof coverings and their performance ratings are given in Appendix A of Approved Document B. Constructions are classified within the National system by 2 letters in the range A to D. The first letter indicates the time to penetration and the second letter is a measure of the spread of flame.

Approved Document B provides guidance on the separation distances according to the type of roof covering and the size and use of the building. There are no restrictions on the use of roof coverings designated AA, AB or AC (National class) or B_{ROOF}(t4) (European class).

4.4 Requirement B5

1. The building shall be designed and constructed so as to provide reasonable facilities to assist fire fighters in the protection of life.

In order to comply with the requirements of B5 buildings with a floor at more than 18m above fire and rescue service access level should be provided with fire fighting shafts which should be equipped with fire mains having outlet connections and valves at every storey. Therefore where a roof is used as an amenity space at a height greater than 18m there should be sufficient dry rising main outlets at roof level such that the 45m hose laying distance is met.

4.5 Recommendations for green roofs

4.5.1 Compliance with requirement B3

In order to comply with this requirement there should be adequate provisions to prevent a fire in the top floor of a building from breaking through the ceiling into the green roof, then spreading horizontally over a compartment wall and back down into an adjacent compartment.

Approved Document B recommends that where compartment walls meet the underside of a roof deck they should be fire–stopped and a zone of the roof 1500mm wide on either side of the wall should have a covering designation AA, AB or AC on a substrate or deck of a material of limited combustibility. If these requirements are complied with then it is considered unnecessary to provide a fire break above a compartment wall.

If the structural base of the roof is designated AA or B_{ROOF}(t4) in accordance with Table A5 of Approved Document B, then the risk of a fire spreading up into the green roof and then down on the other side of a compartment wall is low.

If the structural base of the roof is not listed in Table A5 or is of a lower designation, (eg timber) then a non-combustible strip should be provided, as described above.

Provided that the above recommendations are incorporated into the design of the roof structure then the presence of the green roof will not increase the risk of fire spread above a compartment wall.

The existing design standards and guidance recommend the use of fire breaks around all openings and vertical elements on all types of green roofs. The guidance recommends that the fire breaks should consist of paving slabs or non-vegetated strips of pebbles with a depth of 75mm and diameter between 20 and 50mm for a width of 500mm*. Larger pebble sizes are preferred as this leads to less vegetative growth.

*It may be possible to reduce the dimension of 500mm depending on the type of vegetation used and the climatic conditions however further investigation and evidence would be required to support any reduction from the recommended 500mm fire break.

Whilst fire spread to a green roof via penetrations such as roof lights, pipes or vents in the roof is not in itself a breach of requirements B1 to B5, it is recommended that fire breaks are provided around such penetrations so that basic maintenance procedures can be carried out.

Testing carried out on the growing media using the cone calorimeter showed that for substrates using leaf mould as the organic material ignition occurred at concentrations greater than 50%. The sample containing 100% leaf mould when completely dried was very flammable, which could be seen to represent the fire spread and growth conditions in a forest fire. This however is considered an extreme situation as it is highly unlikely, given the climate in the United Kingdom, that a green roof which has not been maintained and irrigated for a significant amount of time would have dried out to such an extent. Furthermore it is also highly unlikely that the growing media would ever consist entirely of leaf mould.

Nevertheless it is recommended that the recommendations of the existing guidance are followed and that fire breaks are provided in 1m strips every 40m across extensive green roofs.

4.5.2 Compliance with requirement B4

In order to comply with this requirement there should be adequate provisions in place so that a fire in an adjacent building which causes burning brands and/or radiation onto an adjacent building with a green roof will not result in fire spread through the green roof and into the building.

As illustrated in Figure 1 a green roof system consists of a number of layers above between the structural deck and the growth media.

It is considered that if a fire in a green roof only involved the vegetation, for example a bush in an intensive roof or local charring of vegetation, then the risk was negligible as it would be no different from similar vegetation in a normal garden. However if the fire penetrated the growing layer and broke through the roof into the storey below then this would be a breach of Regulation B4.

The large scale testing carried out in this project determined whether there was any fire penetration through the growing media. The European standard DD CEN/TS 1187 was used and this is described in further detail in Appendix A. The test also measured the temperatures at different depths in the growing media to assess whether the temperatures would be high enough to cause ignition of the layers below.

Large scale tests using the European standard DD CEN/TS 1187 were carried out on the growing media used in green roof systems with different concentrations of organic matter. Further details of the test and results are given in Appendix A.3. The test determined whether there was any fire penetration through the growing media and also measured the temperatures at different depths in the growing media to assess whether the temperatures would be high enough to cause ignition of the layers below.

The test did not consider flame spread as there was no vegetation and only the completely dried growing media was used. In the first instance the minimum substrate depth of 80mm was considered.

The tests on the growing media showed that for the most onerous (albeit unlikely) case of a growing medium consisting of 100% leaf mould the temperature at the lowest point in the substrate was not sufficient to ignite the materials used in the layers between the growing media and the roof deck . Consequently a fire on the green roof would not penetrate the layers beneath the growing media and it is highly unlikely that it would penetrate the structural deck below.

In order for green roofs to comply with requirement B4 it is recommended that for all types of green roof the depth of the growing layer should be a minimum of 80mm and the organic content should not exceed 50%.

In accordance with Table 16 of Approved Document B roof coverings with the designation AA, AB or AC are permitted on buildings where the minimum distance from any point on the relevant boundary is less than 6m.

Provided that the structural roof deck complies with requirement B3, ie the roof covering has the designation AA, AB or AC (National class) or B_{ROOF}(t4) (European class) then the testing has shown that the presence of a green roof above the roof covering should not affect the designation and the minimum distances from the relevant boundary given in Table 16 of Approved Document B are still applicable.

4.6 Recommendations for green walls

4.6.1 Compliance with requirement B2

In order to comply with this requirement the wall and ceiling linings should meet the classifications given in Table 10 of Approved Document B. The National classifications are based on tests in the following parts of BS 476: Fire tests on building materials and structures:

- Part 6 – Method of test for fire propagation for products;
- Part 7 – Method of test to determine the classification of the surface spread of flame of products;
- Part 4 – Non-combustibility test for materials; and
- Part 11 – Method for assessing the heat emission from building products.

The European classifications are defined in BS EN 13501-1: 2002, Fire classification of construction products and building elements, Part 1 – Classification using data from reaction to fire tests.

If the use of a living wall system is proposed then test evidence should be provided to demonstrate that it has the appropriate classification for the relevant location in the building. It should be noted however that parts of walls may be of a poorer performance specified in Table 10 of Approved Document B as long as they are not poorer than Class 3 (National class) or Class D-s3, d2 (European class). These areas are limited to less than half the floor area of the room, and cannot be more than $20m^2$ in residential accommodation or $60m^2$ in non-residential accommodation.

If test evidence can be provided that a living wall system meets the Class 3 (National class) or Class D-s3, d2 (European class) classification then it may be used in limited areas within rooms, as described above.

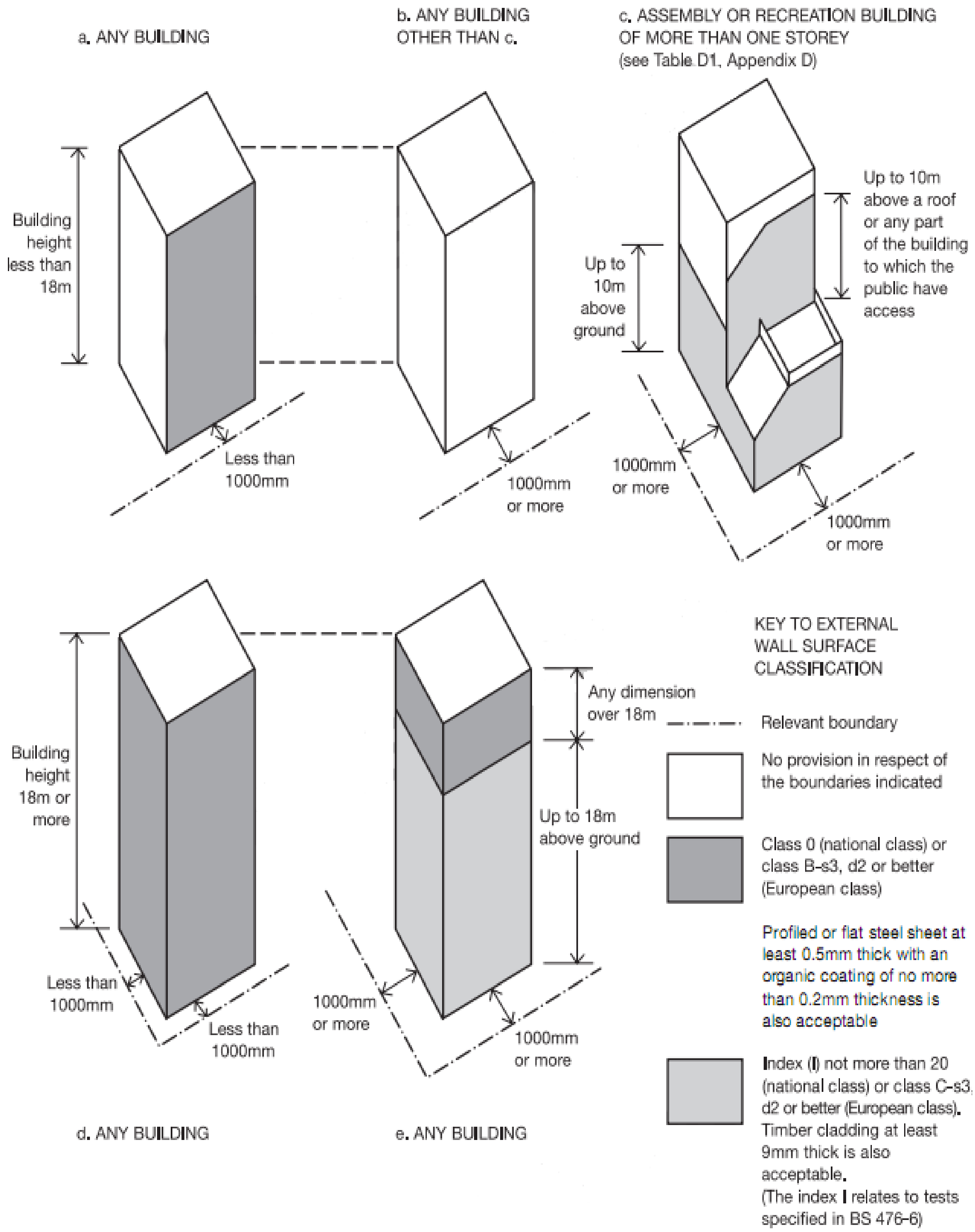
4.6.2 Compliance with requirement B3

In order to comply with this requirement there should be adequate provisions in place so that a fire is prevented from spreading up the wall which could cause the fire to spread from one floor to another across a compartment floor.

Where green wall systems are fixed to a wall which contains compartment floors the guidance in Diagram 33 of Approved Document B should be followed and fire stopping should be provided between the compartment floor and the external wall. The fire stopping should provide the same fire resistance as that required for the compartment floor.

Where a green wall system is fixed to an external wall and a cavity is formed then the size of the cavity should be limited using horizontal and vertical cavity barriers according to the guidance given in Table 13 of Approved Document B.

4.6.3 Compliance with requirement B4



Notes:

1 The national classifications do not automatically equate with the equivalent European classifications, therefore, products cannot typically assume a European class unless they have been tested accordingly.

2 When a classification includes "s3, d2", this means that there is no limit set for smoke production and/or flaming droplets/particles.

Figure 2. Approved Document B Diagram 40 – Provisions for external surfaces or walls

In order to comply with this requirement provisions must be in place to resist the spread of fire up a green wall which could cause radiation and hence fire spread to adjacent buildings.

Approved Document B specifies that external walls should meet the provisions outlined in Diagram 40, which is reproduced in Figure 2. The provisions for the external walls depend on the height of the building, the purpose group and the distance to the relevant boundary.

For all buildings (except assembly and recreation with more than one storey) where the height of the building is less than 18m and the distance to the relevant boundary exceeds 1m there are no provisions (Figure b in Diagram 40). Given that there are no provisions green walls are permitted in such buildings as they would present no greater fire risk than a building façade lined with a combustible material.

Approved Document B also states that in a building with a storey 18m or more above ground level any material used in the external wall construction should be of limited combustibility. Diagram 40 outlines two other provisions for external surfaces (Figures c and e). In assembly and recreation buildings with more than one storey up to a height of 10m, and up to a height of 18m in buildings with a height greater than 18m the external surfaces should have an index (I) not more than 20 (national class) or class C-s3, d2 (European class) as a minimum.

For buildings with a height greater than 18m where the boundary distance is less than 1m and at heights above 18m in tall buildings the external surfaces should be class 0 (national class) or class B-s3, d2 (European class) as a minimum.

Class	Test method(s)	Classification criteria	Additional classification
A1	EN ISO 1182 [a] and	$\Delta T \leq 30$ °C; and $\Delta m \leq 50$ %; and $t_f = 0$ (i.e. no sustained flaming)	-
	EN ISO 1716	$PCS \leq 2,0$ MJ/kg [a] and $PCS \leq 2,0$ MJ/kg [b] [c] and $PCS \leq 1,4$ MJ/m^2 [d] and $PCS \leq 2,0$ MJ/kg [e]	-
A2	EN ISO 1182 [a] or	$\Delta T \leq 50$ °C; and $\Delta m \leq 50$ %; and $t_f \leq 20$ s	-
	EN ISO 1716 and	$PCS \leq 3,0$ MJ/kg [a] and $PCS \leq 4,0$ MJ/m^2 [b] and $PCS \leq 4,0$ MJ/m^2 [d] and $PCS \leq 3,0$ MJ/kg [e]	-
	EN 13823	*FIGRA* ≤ 120 W/s and *LFS* < edge of specimen and $THR_{600s} \leq 7,5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
B	EN 13823 and	*FIGRA* ≤ 120 W/s and *LFS* < edge of specimen and $THR_{600s} \leq 7,5$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
C	EN 13823 and	*FIGRA* ≤ 250 W/s and *LFS* < edge of specimen and $THR_{600s} \leq 15$ MJ	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$mm within 60 s	
D	EN 13823 and	*FIGRA* ≤ 750 W/s	Smoke production [f] and Flaming droplets/particles [g]
	EN ISO 11925-2 [i]: Exposure = 30 s	$F_s \leq 150$ mm within 60 s	
E	EN ISO 11925-2 [i]: Exposure = 15 s	$F_s \leq 150$ mm within 20 s	Flaming droplets/particles [h]
F	No performance determined		

Figure 3. Classes of reaction to fire performance for construction products excluding floorings and linear pipe thermal insulation products

Products are classified in terms of their reaction to fire performance as A1, A2, B, C, D, E, F (A1 being the highest performance and F being the lowest) in accordance with BS EN 13501-1: 2002. This standard references five European test methods for conducting reaction to fire tests, and Table 1 in the standard (reproduced in Figure 3) gives the test methods which should be used to determine the different classes.

Generally any products that have not been tested are considered to be class F. Products then start from the bottom of the table and undergo the EN ISO 11925-2 test which evaluates the ignitability of a product under exposure to a small flame. Products which pass this test are considered to be class E or class D. In order to determine whether the product will give a better performance the single burning item test (BS EN 13823) is then carried out.

The single burning item test has been used in this research to test the green wall systems. This test evaluates the potential contribution of a product to the development of a fire, under a fire situation simulating a single burning item in a room corner near to that product. The test is relevant for classes A2, B, C and D.

Early discussions within the steering group had considered that the main fire risk was the growing medium itself rather than the plants. Cone calorimeter tests were carried out at $50kW/m^2$ on oven dried samples of growing media however no ignition was observed. It was concluded that it is extremely unlikely that the growing medium will ignite or contribute to flame spread, even when completely dried out. Given that none of the green wall systems passed the single burning item test it has been shown that the materials which make up the green wall substrates and containers for the media are combustible even though the growing media is not.

The recommendations for green walls are as follows:

- where the building complies with Approved Document B, Diagram 40b green wall systems can be used
- for other situations where the external surfaces are required to be of limited combustibility then the use of green wall systems are not recommended unless that test evidence can be produced to show that the product complies with the requirements of Diagram 40
- if green wall systems are used where the external surfaces are required to be of limited combustibility then the whole façade should be assumed to be unprotected when calculating the distance to the relevant boundary. If actual position of the relevant boundary is closer to the building then the use of green walls is not recommended.
- as this study has considered a limited number of products and other products are commercially available further testing is required on systems including the growing media and plants.

4.6.4 Installation and maintenance

Some green wall systems are made out of relatively low weight materials such as HDPE and polypropylene however the weight of the system will increase with the addition of growing media, plants and moisture from the irrigation systems.

Some of the lighter weight systems, such those made from HDPE, can be screwed directly to the wall however the manufacturers recommend that they are stacked up to nine units in height. Other systems which are made from panels are heavier and the weight of a single fully saturated panel can be between 50 and 60kg. Green walls should be fixed to walls which have sufficient strength to take the weight of the structure, growing media and plants. The typical weight of a saturated panel measuring 1000mm by 600mm is 50-60kg. Advice should be sought from a structural engineer at the design stage to ensure that this is the case.

Typical green walls are not designed to be “no maintenance” and irrigation is generally required otherwise the plants will not thrive however some systems require less water than others. The living wall systems should be regularly maintained to ensure that the irrigation system is working. Maintenance contracts can be arranged, generally on an annual basis however contracts up to 10 years have been known.

4.7 Property protection

The Building Regulations are concerned with life safety and it is considered that if the guidelines above are followed, the installation of a green roof or wall should not compromise life safety and the functional requirements of the Building Regulations should be met. It is recognised however that property protection should also be considered and where a green roof or wall is proposed as part of a design it is recommended that the insurers should be consulted as early as possible during the design stage.

Appendix A – Experimental Work

A.1 Scenarios considered

A.1.1. Scenario 1

This scenario considers a fire on the top floor of a building with a green roof, where the fire breaks through the ceiling into the green roof, then horizontally over a compartment wall and back down into the adjacent compartment. This would be a breach of requirement B3.

In order to assess the fire risk the structural base of the roof must be considered. If the structural base is made of concrete with a sufficient thickness to provide a substantial fire barrier then it is unlikely that a fire could spread up into the green roof, and then back down to the other side of the compartment wall. Therefore in this instance the risk could be discounted.

If the structural base is constructed from steel sheet or timber then the risk of fire spread could be reduced by providing a non-combustible strip over the line of the compartment wall, as illustrated in Figure A1.

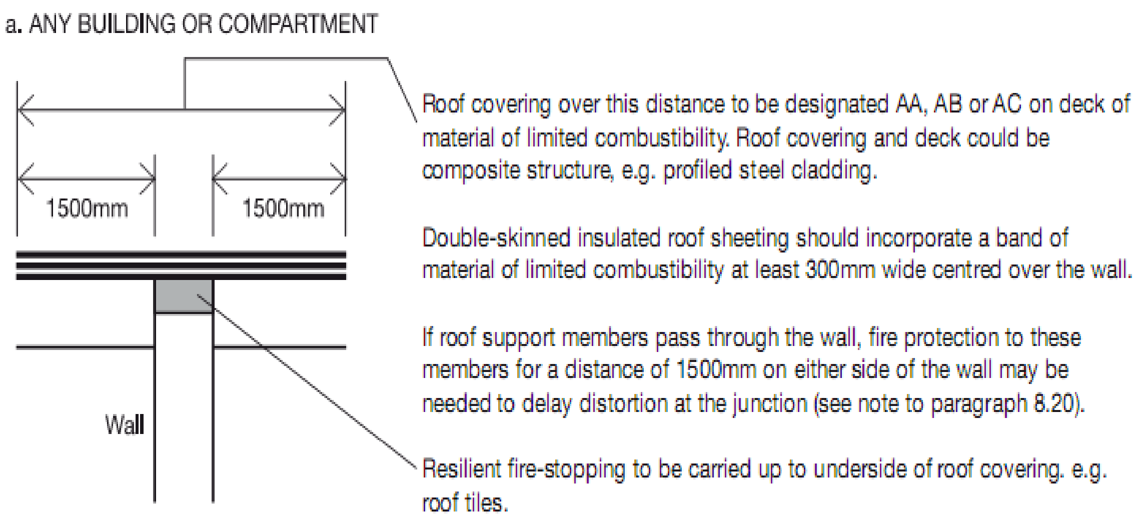


Figure A1. Non-combustible strip above a compartment wall (from Approved Document B, Diagram 30)

A.1.2. Scenario 2

This scenario considers fire spread up a green wall causing radiation and consequently fire spread to adjacent buildings. This would be a breach of requirement B4.

The risk of fire causing green wall panels to fall off the building has also been considered and assessed. It is considered that the risk is no greater with green walls than with other types of construction that use wall panels therefore it has not been considered any further within this project.

The main fire risk is considered to be concerned with the growing medium itself rather than the plants therefore this project does not consider green wall systems where the growing layer is at ground level.

Current methods for assessing external fire spread risk require facades to be considered as protected, unprotected or 50% unprotected. The results of the test will give an indication as to whether green walls can be classified using this approach, however this may be dependent on the manufacturers obtaining specific results under the SBI test.

A similar scenario considers vertical fire spread up a green wall causing fire to spread from one floor to another across a compartment floor. This would be a breach of requirement B3.

The risk of fire spread up a cavity between the green wall panels and the façade behind has been considered as some types of green wall system do have such a cavity. Approved Document B controls this risk by requiring cavity barriers (horizontal and vertical) in similar situations. The fire risk in the cavities can therefore be controlled by complying with the requirements of Approved Document B however the design should be included at an early stage of the project.

A.1.3. Scenario 3

This scenario considers a fire in an adjacent building where burning brands and/or radiation onto an adjacent green roof causes fire spread to the building with the green roof. This would be a breach of requirement B4.

If the fire in the green roof only involves the vegetation on the green roof, for example a bush in an intensive roof, or local charring of vegetation, then this would be no different from similar vegetation in a normal garden, and would not be a significant risk. However if the fire then broke back down into the building below the green roof this would require fire spread down through the green roof itself.

In order to determine whether this was a credible risk small scales tests were carried out on the growing layer using the cone calorimeter, varying the organic content of the layer. The impact of different thicknesses of growing layer was also assessed using DD CEN TS 1158 (test 4).

A.1.4. Scenario 4

This scenario considers the fire spread from within the building to a green roof via penetrations such as roof lights, pipes or vents in the roof. Fire spread to a roof by this mechanism would not in itself be a breach of B1 to B5 of the Building Regulations however it would be a breach if the fire spread across a compartment wall, which is covered by Scenario 1.

This risk is mitigated in existing design standards by requiring horizontal strips of gravel (or similar non-combustible construction) around rooflights, although other openings such as pipes and vents are not covered). In addition, they also require horizontal strips at approximately 40m intervals to prevent significant horizontal fire spread across a roof.

A.2 Cone calorimetry

A.2.1. Green roof systems

Tests were carried out on samples of growing media that had been dried out using a conditioning room and an oven at 40°C.

The fire tests aimed to examine the effect on the fire performance by varying factors such as the amount of organic content and the type of organic and inorganic content used.

Small scale testing was carried out using cone calorimetry. The organic materials used were standard mix, leaf mould and recycled compost. The inorganic materials used were crushed brick and pumice.

The main conclusions from the cone calorimeter tests were as follows:

1. no ignition occurred for substrates using the standard organic mix even when they were completely dried.

2. for a completely dried 100% standard organic mix substrate where ignition occurred the flame spread could not be sustained because the peak heat release rate was 55 kW/m^2.

3. for substrates using leaf mould as the organic material ignition occurred at concentrations greater than 50%. The sample containing 100% leaf mould when completely dried was very flammable, which could be seen to represent the fire spread and growth conditions in a forest fire.

A.2.2. Green walls growing media

Cone calorimetry was carried out on samples of a growing medium for living walls. The growing medium consisted of medium textured peat and coir with added wood fibre, perlite, lime base nutrients and CRF fertiliser with added wetter and insect control.

The material was dried in an oven at 40°C before carrying out the cone calorimeter test at $50kW/m^2$. A total of three tests were carried out on the samples. No ignition was observed to have occurred in any of the tests and there were no signs of possible ignition, therefore the reactions were considered as non-flaming.

It is therefore unlikely that the growing medium will ignite or contribute to flame spread, even when completely dried out.

A.3 Large scale testing

Large scale tests were carried out on the growing media used for green roofs using DD CEN/TS 1187. These tests reviewed a similar range of factors and also assessed the depth of the organic layer. The intention of this test was to determine whether a fire impacting on the surface of the roof, for example due to burning brands from an adjacent building, could cause fire spread down through the layer into the building below.

All tests were carried out at an angle of 20° to the horizontal. Tests were initially carried out on 80mm thick samples, which is the minimum thickness recommended. Further testing (at 120mm and 150mm depths) would only be carried out if the tests for the depth of 80mm samples indicated ignition. The purpose of the test was to determine whether the temperature rise at the base of the sample would be sufficient to cause ignition of any of the layers below. Four thermocouples were placed in each specimen in order to measure the temperature variation with depth.

For all of the samples tested some smoking did occur and glowing was observed on the surface of the samples however after 60 minutes there was no fire penetration at the base of the sample. The temperatures measured at the lowest point in the substrate were generally less than 100°C except for the sample that consisted entirely of 100% completely dried out leaf mould, which gave a temperature of 218°C at the lowest point. It should be noted however that the materials used in green roof systems below the growing layer are typically polymers and the piloted ignition temperature of these polymers is greater than 218°C therefore it is unlikely that even in the most onerous case, where a substrate consisted of completely dried leaf mould, that ignition of the green roof substrate would occur.

Large scale testing was also carried out on five entire built-up "off the shelf" green wall systems using BS EN 12823 – the single burning item test. The systems tested are listed below however it should be noted that no plants were installed in any of the systems.

Supplier	**Description**
Biotecture	Hydroponic system. HDPE boxes filled with horticultural rockwool
ANS	Substrate filled HDPE modules
Optigreen	Aluminium mesh cassette filled with growing medium
Cityroofs	Porous plastic irrigated boards
Mini Garden	Stacked HDPE planters filled with growing medium

Table A1. Commercially available green wall systems tested

For all five systems that were tested the fire growth rate index (Figra), the total heat release, smoke growth rate (Smogra) and the total smoke production could not be calculated. This was because the tests had to be terminated before 10 minutes. For three of the samples the test was terminated due to the heat release exceeding 350kW and for two of the samples the test was terminated because the specimens collapsed onto the burner.

The calculations for Fire Growth Rate Index and Smoke Growth Rate also rely on the test being conducted for more than 300 seconds and in four out of the five specimens the test was terminated before this length of time. Given the above results it can be concluded that all of the systems in this study failed the test.

A.4 Conclusions

In general the growing medium used in both green roofs and green walls cannot be ignited and flame spread does not occur. Furthermore the temperatures obtained at the lowest point in the green roof substrate are not high enough to result in ignition of the materials used below the growing layer.

Ignition only occurred when the growing medium consisted of 100% leaf mould, which had been completely dried out. In addition this sample gave the highest temperature at the lowest point in the substrate however the temperature would not be sufficient to ignite the materials used below the growing layer. In reality it is highly unlikely that the growing medium would consist of 100% leaf mould.

The growing medium used in living walls cannot be ignited, even when completely dried out.

The materials used to make up the living wall structures can be ignited and the heat release from three of the samples was greater than 350kW.

The study has only considered five commercially available systems and it should be noted that other systems are available. It was originally assumed that the main fire risk in green wall systems was growing media rather than the plants however the testing has also shown that the materials which support and contain the growing media may also contribute to flame spread. Further research is required on the different systems and should consider testing on systems populated with plants.