Impact of fire on the environment and building sustainability

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Executive summary

This is the final research report of a project entitled *Scoping study on the impact of fire on the environment and building sustainability* commissioned by Communities and Local Government and carried out by BRE.

The changes to the 1984 Building Act that came about from the Sustainable and Secure Buildings Act 2004 mean that the locus of Approved Document B could be extended beyond life safety to cover issues relating to environmental protection, sustainability and security. The subject of fire and the environment and building’s sustainability is potentially wide ranging and covers a large number of issues.

In recognition of this, Communities and Local Government identified a need to commission this scoping study to identify the potential impact of a building fire on the environment and the impact of fire protection on the environment (i.e. the environmental impact of providing fire safety components and systems in a building) and the scope for addressing such issues through the Building Regulations or another suitable vehicle, such as the Code for Sustainable Homes.

The scoping study has demonstrated that is not possible, with our current state of knowledge, to recommend any particular course of action other than further directed research.

For Communities and Local Government, the development of a transparent, effective and robust Cost Benefit (or CO2/Benefit) Analysis tool will underpin further developments. The core elements of such a tool exist. The tool might be deployed in one of three ways:

1. by permitting a generic analysis against each purpose group, leading to (purpose group-based) revisions to Approved Document B which offer improved environmental protection (or reduced environmental impact).

2. by permitting a specific analysis for each individual building project so that the environmental impact of the fire protection in that specific building might be assessed, and optimised, to minimise environmental impact. Such an analysis might be integrated with existing methodologies, such as BREEAM or for domestic buildings; the Code for Sustainable Homes.

3. to determine the environmental impact of any proposed changes to Approved Document B.

The key is sound data; data that at present does not exist, or exists only in a form that needs extensive processing. Of particular significance is the quantification of the building stock, for each purpose group. These values may be impossible to obtain and an alternative approach, based on sensitivity analysis and threshold values, may be adequately effective.

This report contains the analysis and a number of conclusions of the scoping study, implications for Communities and Local Government and recommendations for potential areas of further work.
The conclusions and recommendations of this scoping study provide clear information to assist Communities and Local Government in developing their priorities for future research on how (or whether) to include environmental protection and sustainability in Approved Document B and how (or whether) to include the impacts of fire in the Communities and Local Government wider sustainability agenda for buildings and construction.
## Contents

1. Introduction and objectives  
2. Programme of work  
   2.1 Identification of issues and collection of relevant information  
3. The potential impact of a building fire on the environment  
   3.1 The discharge of the products of combustion into the atmosphere (from uncontrolled fires, especially large ones and fires controlled by suppression systems)  
   3.2 The potential contamination of groundwater and land from fire-fighting run-off (from manual fire-fighting and fixed suppression systems)  
   3.3 The reinstatement of the building and the disposal of fire damaged structure  
   3.4 The potential contamination of land from fire residues  
   3.5 Current relevant ISO activities  
   3.6 Other work  
4. The impact of fire protection on the environment  
   4.1 The potential benefit of fire protection, such as sprinklers or additional compartmentation, in controlling/limiting the size of fires (and hence, reducing the environmental impact of the actual fire)  
   4.2 The 'cost' of embodied energy and other impacts in the manufacturing and use of components for fire protection systems  
   4.3 Automatic sprinkler systems  
   4.4 The BRE environmental profiles methodology  
   4.5 Current relevant activities in CEN fire safety arena  
5. Specification for a cost benefit analysis tool  
   5.1 The current version of the cost benefit analysis tool  
   5.2 Assumptions in the risk/CBA tool  
   5.3 Consideration of the inclusion of environmental impact issues in the CBA tool  
   5.4 Assigning monetary value to environmental impacts  
   5.5 Relevant international studies  
6. Inclusion of fire safety in environmental/sustainability tools  
   6.1 Existing environmental and sustainability tools  
   6.2 Inclusion of fire safety within Type 1 (Building Assessment) tools  
   6.3 Inclusion of fire safety within Type 2 (Detailed Design) tools  
   6.4 Inclusion of fire safety within Type 3 (Early Design) tools  
   6.5 BREEAM In-Use  
   6.6 Weightings for BREEAM schemes  
   6.7 Derivation of the BREEAM category weightings  
   6.8 Incorporation of environmental data into fire tools  
7. Consideration of the assessment baseline/target  
   7.1 Option 1  
   7.2 Option 2  
   7.3 Option 3  
   7.4 Option 4  
   7.5 Option 5a  
   7.6 Option 5b
<table>
<thead>
<tr>
<th>Page</th>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>General discussion</td>
<td>56</td>
</tr>
<tr>
<td>9</td>
<td>Conclusions</td>
<td>58</td>
</tr>
<tr>
<td>10</td>
<td>Potential areas of further work</td>
<td>61</td>
</tr>
<tr>
<td>11</td>
<td>Acknowledgements</td>
<td>69</td>
</tr>
<tr>
<td>12</td>
<td>References</td>
<td>69</td>
</tr>
</tbody>
</table>

Appendix A – Chart showing an indication of the scale and nature of the current knowledge gaps
1 Introduction and objectives


The subject of fire and the environment and building’s sustainability is potentially wide ranging and covers a large number of issues. In recognition of this, Communities and Local Government identified a need for a scoping study to identify the potential impact of a building fire on the environment and the impact of fire protection on the environment (i.e. the environmental impact of providing fire safety components and systems in a building) and the scope for addressing such issues through the Building Regulations [4] or another suitable vehicle, such as the Code for Sustainable Homes [5].

The conclusions and recommendations of this project are required to provide clear information to assist Communities and Local Government in developing their priorities for future research on how (or whether) to include environmental protection and sustainability in Approved Document B and how (or whether) to include the impacts of fire in the Communities and Local Government wider sustainability agenda for buildings and construction.

The overall aim of this project is to identify the potential impacts and the scope for addressing environmental and sustainability issues in relation to fire and fire protection through the Building Regulations or another suitable vehicle such as the Code for Sustainable Homes.

The specific objectives of this project are:

a. To identify the potential impact of a building fire on the environment and the broader objectives of sustainable construction.

b. To consider the specification for the development of a Cost Benefit Analysis model for assessing these impacts.

c. To identify implications for Communities and Local Government in terms of the Building Regulations or other mechanisms for change.

d. To identify potential areas for further work (e.g. development of guidance).

To achieve these objectives, the project is divided into six tasks: Task 1 Identify issues and collect relevant information, Task 2 Review and identify the potential impact of a building fire on the environment, Task 3 Review and identify the impact of fire protection on the environment, Task 4 Specification for cost benefit analysis tool, Task 5 Inclusion of fire safety in environmental/sustainability tools, Task 6 Produce Final research report.

This project does not involve an industry Stakeholder Group.

Two key themes have been identified:

a) the impact of a building fire on the environment and

b) the impact of fire protection on the environment (i.e. the environmental impact of providing fire safety components and systems in a building)
This is the final report of the project which contains the analysis and conclusions of the scoping study, implications for Communities and Local Government and recommendations for potential areas of further work.

2 Programme of work

2.1 Identification of issues and collection of relevant information

Relevant information was collected for the project using BRE experts’ knowledge, library and web searches and directly from BRE contacts. The information collected was reviewed and gaps in the knowledge that need to be researched have been identified.

BRE experts have comprised BRE fire safety specialists and BREEAM environmental impact and sustainability specialists. This was essential to the outcome of this project.

A structured ideas workshop of ten BRE experts was held on 13 October 2008 to identify the issues for this scoping study and to determine where to focus the remainder of the activity. B Martin, the Communities and Local Government Project Officer attended. The workshop and the interaction of the participants generated lots of discussion and ideas for the project.

The subject of the impact of fire on the environment and building sustainability is potentially wide ranging and covers a large number of issues. The project covers buildings in all Approved Document B purpose groups, all types of building fires, and all types of passive/active fire protection systems. It is likely there are gaps in knowledge and there is a lack of quantitative information in key areas. This is a scoping study and is not about solving the issues once they have been identified.

It was concluded that the subject of the impact of sustainability on the environmental impact of a fire is a separate issue and should not be considered in this project.

Further research would determine whether fire protection systems are better for the environment or not. It was agreed that whatever the outcome of any further research, it must, in due course, be able to be incorporated into Approved Document B. Guidance must be based on building type rather than building usage. It was noted that the purpose of this study is to set recommendations for further study, not to set the actual guidance.

The main findings of the workshop were as follows:

- Fire/environment life cycle diagrams have been developed here which are useful for considering a) the normal cycle without fire (construction, occupation and demolition) and b) the normal cycle with fire (construction, occupation, fire, rebuild, second use, demolition) and for making comparisons (see Figures 1 and 2). This included consideration of the environmental impact of fire protection systems. The frequency of the fires must be taken into account as well as the number of buildings, new constructions, refurbishments, etc.

- There are current relevant ISO (International Standardisation Organisation) activities under ISO/TC92/SC3 (Fire threat to people and the environment) and WG6 (Environmental impact of fire effluents) which includes the development of
Guidelines for assessing adverse environmental impact of fire effluents (Guidelines (see Figure 3) and quantification of impact) and also for the mitigation and containment of fire-fighting water run-off. These are not yet published. ISO/TC61 (Plastics) has an environmental brief and has produced documents.

- Quantitative risk assessment and the current BRE Cost Benefit Analysis tool currently include the impact of a building fire on the environment in a simple way. New input data are required for environmental impacts and the environmental impact of sprinklers.

- BREEAM Environmental impact assessment techniques exist. ‘Systems’ are modelled using Life Cycle Assessment (LCA). In principle, the inputs could be altered to model fire scenarios. Input data for fire and fire protection systems are needed. LCA could be used to assess impacts of different fire systems within a fire scenario. Currently, the BRE Environmental Profiles methodology considers thirteen impact categories and relates everything to a weighted, normalised unit, the Ecopoint.

- Potential solutions and suggestions for the way forward for this project were, as follows:
  - There is a need to know about any relevant international projects and activities.
  - A research programme should be recommended to further develop LCA to include fire.
  - Boundaries and inputs/outputs from fire need to be defined though information on fire products exists.
  - Environmental factors could influence Approved Document B.
  - Quantifying environmental impact could be difficult. Carbon dioxide/economic equivalence is preferable for simplicity. The possibility of using Ecopoints was raised as an alternative approach.
  - There is a need to share information across the specialisms to maximise potential for identification of avenues of research.
  - It was questioned whether it is possible to assign a relative monetary value to each of the LCA outputs used by the current schemes to allow Cost Benefit Analyses to be undertaken.
  - Harmonised outcomes from LCA need to be incorporated into probabilistic Cost Benefit Analysis tools.

A final meeting of five BRE experts was held on 18 June 2009 to discuss and agree potential areas of further work and potential mechanisms for change.
(Normal) life cycle – Full cycle

Figure 1 The normal life cycle of a building (without fire)

(With fire) life cycle – full cycle

Figure 2 The normal life cycle of a building with fire
Figure 3 Illustration of environmental aspects associated with a fire event (BRE version of ISO diagram)
3 The potential impact of a building fire on the environment

The potential impact of a building fire on the environment has been considered. The issues for the potential impact of a building fire on the environment include:

- The discharge of the gaseous and particulate products of combustion into the atmosphere (from uncontrolled fires; especially large ones, and fires controlled by suppression systems).
- The use of water in manual fire-fighting and water based suppression systems.
- The potential contamination of groundwater and land from fire-fighting run-off (from manual fire-fighting and suppression systems).
- The reinstatement of the building and the disposal of fire damaged structure.
- The potential contamination of land from fire residues.

Note: The project proposal included assessment of the innovative materials used in meeting the sustainability agenda and their potential fire performance. However, it was agreed during the structured ideas workshop that this is a separate issue and is considered to be outside the scope of this project.

3.1 The discharge of the products of combustion into the atmosphere (from uncontrolled fires, especially large ones and fires controlled by suppression systems)

Details on the effects of common products of fire, such as NOx, SOx, Polycyclic Aromatic Hydrocarbons, and dioxins are readily available [6 – 12]. The toxicology impact of many of these compounds on humans and wildlife has been studied [6], [11], [13 – 16]. In particular, research has been conducted into the production of carbon monoxide (CO) and carbon dioxide (CO₂) [17 – 20], including their ratios [19] and the transport of CO on a global scale [21]. There are also some data on the products of common plastics fires [22], and some experimental work has been carried out to quantitatively analyse and measure the products of electronics fires [20]. In particular, work has been undertaken to assess the environmental impact of PVC fires as part of a life cycle analysis of PVC [23]. This work focussed on the release of HCl, phosgene gas and dioxins and their human health effects, not the environmental impact as a whole. The discharge of particulates has been studied [24 – 26]. However, a study aiming to provide fuel-based emission factors for particulate emissions did not consider all combustion sources (and did not include building fires):

“The following combustion sources that have the most significant relative contribution to air pollution and result in exposures and risks to large air pollution and result in exposures and risks to large populations will be discussed in this paper: road transport, power plants and industrial combustion classified as industrial facilities, small combustion (domestic, commercial, public and agricultural combustion sources), environmental tobacco smoke (ETS) and vegetation burning. Not considered here are sources which have small global contributions, or which are
unique to specific local areas. Thus the sources not discussed include, for example, off-road transport, fireworks displays or ritual or religious burning". [25]

For the discharge of the products of combustion into the atmosphere fires controlled by suppression systems, see section 4.1.

Manual fire-fighting and water based suppression systems necessarily require, often substantial, quantities of water (and sometimes other agents) to fight a fire. The use of this water will have an environmental impact in terms of the energy used in storing and discharging the water. However, it is commonly assumed that the benefits (including environmental benefits) of fighting fires will usually outweigh the disbenefits of allowing fires to run a natural course. Additionally, in some circumstances, water can be taken from 'sustainable sources', for example, from lakes or canals, and be used to tackle fires without any significant impact on the water source. However, it is also recognised that this may not be the case in all fire situations. There have been instances where the water damage resulting from the operation of a water based active suppression system has caused significant and costly damage to buildings and contents, and with the concomitant environmental impact.

3.2 The potential contamination of groundwater and land from fire-fighting run-off (from manual fire-fighting and fixed suppression systems)

Seven research papers were found on the damage caused by the chemicals used in fire-fighting foams and powders [27 – 33]. Of these, two [27, 33] were specific studies on the contamination of groundwater as a result of fire fighting run-off, including quantitative analysis of some of the compounds in groundwater. The toxicological impact of this on humans is considered in all of these studies, but the long and short term environmental impact as a whole is only assessed in three [30 – 32] of these. There is also evidence of testing of the emission of volatile organic compounds, polycyclic aromatic hydrocarbons, heavy metals and flame retardants from electronic equipment to which water has been applied [19]. This study, however, assesses only the emissions and not their environmental impact.

Some manual and automatic fire-fighting systems also use other agents, including foams. The environmental impact with the use of such agents may be significant, but again, additive agents are usually used to aid the effectiveness of the system in fighting a fire. The use of agents must therefore be considered, in terms of the potential benefits of enhanced fire-fighting effectiveness balanced against the potential environmental impact on the ecological systems affected by the water run-off, etc. There are a number of foam products available for fire-fighting purposes that have a range of potential environmental impacts, some being more environmentally ‘friendly’ than others [34].

UK Fire and Rescue Services are becoming increasingly aware of their impact on the environment, particularly in terms of carbon impact [35, 36]. Metropolitan Fire and Rescue Services are known to have individuals tasked with the specific role of identifying and quantifying the environmental impacts of both the day-to-day and incident associated activities and so are developing their own databases. Information from these sources would be extremely useful but it is anticipated that it would need to be expanded upon to reflect the influence of fire size on environmental impact by the Fire and Rescue Service, and to ensure that all of the relevant environmental impacts are assessed by all Fire and Rescue Services.
3.3 The reinstatement of the building and the disposal of fire damaged structure

More than ten papers on the post-fire behaviour of concrete [37 – 48] were found but no information was found on any other building materials. Also, there are no available statistics to indicate how many fires result in the demolition and rebuild of a building, and how many can be reused. No information was found on the environmental difference between the demolition of a building at its end-of-use and demolition after a fire. There is also the need to find the environmental difference between disposing of different types of building materials.

3.4 The potential contamination of land from fire residues

More than ten studies and reports were identified on the environmental impact of flame retardants [49 – 60]. These include the hazards of traditional flame retardants [49], [51], [53], [58], [59] and the reduced impacts of new ones [52], [55]. There is also a wealth of information on the environmental damage caused by heavy metals [61 – 65], and even a suggestion that the quantity of heavy metals in soil after a fire could be used to make an ecological assessment of the pollution caused by a fire [22], [66]. (See also section 4.4). There are, in any case, widespread concerns regarding the environmental and health implications from fire retardants which appear to be entering the food-chain under normal (i.e. non-fire) conditions, e.g. by washing. These issues lie at the limits of this scoping study and have not been reviewed here.

3.5 Current relevant ISO activities

There is work currently being undertaken in ISO to develop International standards under ISO/TC92 (Fire Safety) which are relevant. Much of this work is not due to be published for some time, mainly incomplete and not in the public domain. A brief summary is given, as follows.

Three documents are being drafted in ISO/TC92/SC3/WG6 (Environmental impact of fire effluents), a Task Group of ISO/TC92/SC3 (Fire threat to people and the environment) and are relevant to this study. These are:

- Guidelines for assessing the adverse environmental impact of fire effluents – Part 1: Fundamentals [67].
- Guidelines for assessing the adverse environmental impact of fire effluents – Part 2: Quantification of impact [68].
- Guidelines for mitigation and containment of fire-fighting run-off [69].

Part 1 of the guidelines describes the chemical and physical mechanisms of effluent production in the various stages of the fire. These are:

- Direct gaseous and particulate emissions to the atmosphere (fire plume).
- Spread of atmospheric emissions.
- Deposition of atmospheric emissions.
- Soil contamination (from fire-fighting water run off and extinguishing media).
• Ground and surface water contamination (from fire-fighting water run off and extinguishing media).

The effects of intervention are discussed, including prevention, detection, containment and mitigation as well as fire-fighting. The emissions to the air are considered, as are the pathways by which harm is caused to the environment, buildings and health. The terrestrial emissions cover fire-fighting and clean-up operations, interaction with weather conditions, as well as the direct emissions from fire. The emission to the water environment section includes the effects of contaminated water run-off, foam and chemicals on terrestrial water sources, coastal waters and sewerage treatment works. The short and long term effects are considered.

The guidelines for assessment of environmental impact include sampling of air, water and soil, and analysis for a range of compounds. There are also case studies presented, and an overview of current regulations and guidance documents.

Part 2 of the guidelines for assessing the adverse environmental impact of fire effluents is expected to contain guidance for the quantification of environmental impact, but there is currently no available information on this document.

The guidelines for mitigation and containment of fire-fighting run-off document will be far more detailed than the previously described “fundamentals”, but is currently far less developed, and is expected to be published after two to three year’s time. The sections will cover: emissions to the aquatic environment; control of fire water run-off with regards to surface water, ground water and particular consideration given to commercial and industrial sites; environmental damage limitation covering controlled burns and risk reduction strategies (prevention, detection, containment and mitigation). This document will contain case studies similar to its companion standard Part 1, but with more detail specifically concerning treatment of water run-off.

ISO/TC61 (‘Plastics’) also has an environmental brief and has produced documents.

3.6 Other work

Other work that was found which considers environmental impact of fires was on the subject of wildfires. Fourteen research papers were identified on this subject, published within the last year [70-82].

Information has been sought regarding the environmental impact, and the environmental impact analysis carried out, for a range of commercial “combustion” processes, and which include coal fired combustion power stations and waste-to energy power stations (such as those scrap using tyres). However, at the time of writing, no systematic analysis has been located in the public domain.
The potential impact of fire protection on the environment has been considered. The issues for the impact of fire protection on the environment include:

- The potential benefit of fire protection, such as sprinklers or additional compartmentation, in controlling/limiting the size of fires (and hence, reducing environmental impact)
- The ‘cost’ of embodied energy and other environmental impacts from the manufacturing and use of components for fire protection systems (automatic sprinkler systems, automatic fire detection systems and passive fire protection components, e.g. compartment walls and built in fire protection).

### 4.1 The potential benefit of fire protection, such as sprinklers or additional compartmentation, in controlling/limiting the size of fires (and hence, reducing the environmental impact of the actual fire)

The main types of fixed fire suppression systems installed in buildings are: automatic sprinkler systems, water mist systems and gaseous extinguishing systems. Other systems are foam systems and aerosol systems but their use is limited. Portable fire extinguishers use similar media to fixed systems, including water, foam, powder and halocarbon.

The potential benefit of installing sprinklers in a building to reduce environmental impact is by controlling, suppressing and, in some cases, extinguishing the fire. This could result in reducing the size of the fire (limiting fire damage to building materials) and reducing the rate of smoke production/gases emitted, in terms of heat, carbon dioxide and other chemical species, reduce the requirements for fire-fighting operations, limit the impact and disruption on the community affected by a fire and other indirect losses and reduce the energy and resources required to clear, reconstruct or reinstate a building.

There are a number of research studies that could provide data on fire damaged area and fire size with and without sprinklers [e.g. 83, 84].

There have been some calorimeter studies that could provide data on heat release, carbon dioxide, carbon monoxide and oxygen during the fire from sprinklered and equivalent unsprinklered fires [e.g. 85-95].

The same principles apply to other suppression systems, e.g. water mist systems [e.g. 96, 97, 98].

The potential benefits of compartmentation (or additional compartmentation) are similar; these products reduce the opportunities for the fire to grow or, if particularly effective, may starve the fire of air so that it goes out. In any case, passive systems limit the extent of fire spread, or the speed of fire spread, and reduce the amount of damage.

Automatic fire detection and alarm systems protect lives but have no impact on the fire development (other than, potentially, resulting in a more rapid response by the Fire and Rescue Service).
The ‘Characterisation of fires for design purposes’ project was undertaken by BRE for Communities and Local Government (formerly DTLR) [89]. The aim of the project was to obtain quantitative data on the growth rates of a number of realistic design fires; these data could then help fire safety engineers, designers and regulators when they design fire safety systems. The object was to establish a database of specific fire characteristics for at least 12 realistic fire scenarios; characteristics included heat release rates, mass flow rates, smoke production rates, CO/CO₂ ratios and gas concentrations, with and without sprinklers.

These calorimeter studies characterised sprinkled and unsprinkled fires and concentrated on fire growths and control by sprinklers for the following occupancies: offices (cellular and open plan arrangements), retail (carpet displays, luggage displays, sports clothing, soft toy mountains, stacked wooden pallets, idle cardboard boxes, handcart), libraries (video and CD displays), soft play area, office reception area, nightclub/theme bar.

Fire engineering assessments frequently depend upon assumptions made about the rate of fire growth. This is important to the design of the means of escape, particularly where smoke control is involved, and to the assessment of structural fire resistance. Since there is a limited number of accepted design fires at present, their applicability to particular situations is uncertain; these data are an important influence, therefore, in developing a consensus on the underlying design fire assumptions.

4.2 The ‘cost’ of embodied energy and other impacts in the manufacturing and use of components for fire protection systems

The ‘cost’ of embodied energy and other environmental impacts from the manufacturing and use of components for fire protection systems such as automatic sprinkler systems, automatic fire alarm and detection systems, smoke control systems and passive fire protection systems could be determined using the BRE Environmental Profiles methodology [99]. (See sections 4.4 and 6). The whole building embodied impact software tool “Envest2” [100] (see section 6) has been developed by BRE. This can incorporate data from Environmental Certification [101] (see section 6). For the Environmental Profiles methodology, the fire protection systems need to be divided up into their constituent elements/components.

The components of sprinkler, water mist, and gaseous extinguishing systems are described in section 4.2.1, 4.2.2 and 4.2.3, respectively.

The components of passive fire protection, fire detection and alarm systems and smoke control systems are described in sections 4.2.4, 4.2.5 and 4.2.6, respectively.

4.3 Automatic sprinkler systems

An automatic sprinkler system typically consists of a water supply, control valves, an alarm and an array of pipework fitted with individual sprinkler heads (see Figure 4). The sprinkler heads are mounted at specific appropriate locations, e.g. beneath a roof or ceiling or within a racking system.
There are a number of different types of water supplies that can be used for sprinkler systems. These include: town mains; storage tanks (pump suction tanks, gravity tanks, reservoirs); inexhaustible sources (e.g. rivers or lakes); and pressure tanks. Some of these options are used in conjunction with pumps and some may require booster pumps. Pipework materials include: steel, copper and fire rated CPVC plastic. Pumps can be electric or diesel.

### 4.3.1 WATER MIST SYSTEMS

A water mist system is a fixed fire protection system, comprising components for automatic detection and actuation, water supply delivery and water atomisation. A water mist system discharges a spray of small water droplets. They can be categorised by reference to the following key components:

- Fire fighting medium - potable water, water with antifreeze, water with additive, water with inert gas.
- Detection – automatic quick response glass bulb nozzles, smoke detectors and actuators, with or without cover plates, alarms and control panel and alarm system.
- Atomisation – nozzle and orifice, filters and strainers, single fluid system, twin fluid system, low, medium and high pressure.
- Delivery - wet pipe system, dry pipe system, pre-action system, deluge system, pipe (material e.g. stainless steel, fire rated CPVC plastic, copper, supports).
- Supply – storage vessel (e.g. tanks, cylinders), towns’ mains, propellant (e.g. nitrogen), pumps.
Most water mist systems for use in residential buildings will be low pressure, wet pipe systems, with automatic, quick response glass bulb nozzles, supplied by cylinders or tanks containing potable water.

![Diagram of a water mist system in a residential premises showing a pump and tank arrangement](image)

**Figure 5** An example layout of a water mist system in a residential premises showing a pump and tank arrangement

An example layout of a water mist system in a dwellinghouse, showing pressurised water cylinders and optional mains water supplies, is shown in Figure 5.
4.3.2 GASEOUS FIRE EXTINGUISHING SYSTEMS

A gaseous fire extinguishing system generally comprises of one or more containers of pressurised gas, connected to pipework feeding nozzles within the hazard enclosure. The containers are fitted with valves that can be electrically, pneumatically or manually operated. Most systems have automatic operation. An automatic system utilises fire detection, alarm and control units.

The extinguishing gases used in the systems can be categorised into two distinct classes: inert and halocarbon. Inert gases (e.g. argon, nitrogen and mixes) are unreactive gases that act primarily by oxygen displacement. The halocarbon gases, e.g. hydrofluorocarbons and perfluoroketones, act largely by heat absorption, they have some chemical effect on the flame combustion reactions. Table 1 lists some of the extinguishing gases available in the UK.

Table 1 Extinguishing gases used in fixed gas extinguishing systems

<table>
<thead>
<tr>
<th>Designation</th>
<th>Composition</th>
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<tr>
<td>INERTS</td>
<td></td>
</tr>
<tr>
<td>IG-01</td>
<td>Ar</td>
</tr>
<tr>
<td>IG-100</td>
<td>N\textsubscript{2} \textsuperscript{Currently, rarely used}</td>
</tr>
<tr>
<td>IG-541</td>
<td>N\textsubscript{2} (52 vol %), Ar (40 vol %), CO\textsubscript{2} (8 vol %)</td>
</tr>
<tr>
<td>IG-55</td>
<td>N\textsubscript{2} (50 vol %), Ar (50 vol %)</td>
</tr>
<tr>
<td>HYDROCARBONS</td>
<td></td>
</tr>
<tr>
<td>Hydrofluorocarbons</td>
<td></td>
</tr>
<tr>
<td>HFC-125</td>
<td>CF\textsubscript{3}CHF\textsubscript{2} \textsuperscript{Currently, rarely used}</td>
</tr>
<tr>
<td>HFC-23</td>
<td>CHF\textsubscript{3}</td>
</tr>
<tr>
<td>HFC-227ea</td>
<td>CF\textsubscript{3}CHF\textsubscript{CF}</td>
</tr>
<tr>
<td>HFC-236fa</td>
<td>CF\textsubscript{3}CH\textsubscript{2}CF\textsubscript{3} \textsuperscript{Currently, rarely used}</td>
</tr>
<tr>
<td>Perfluoroketone</td>
<td></td>
</tr>
<tr>
<td>FK-5-1-12</td>
<td>CF\textsubscript{3}CF\textsubscript{2}C(O)CF(CF\textsubscript{3})\textsubscript{2}</td>
</tr>
</tbody>
</table>

Inert gases are neither ozone depleting substances nor greenhouse gases and, as such pose no risk to the environment.

The environmental factors to be considered for halocarbons are ozone depleting potential, global warming potential and atmospheric life time. Table 2 presents the environmental impacts of the halocarbon gases. None of these halocarbons have an ozone depleting potential.
Table 2 Environmental factors for halocarbon gas extinguishing systems

<table>
<thead>
<tr>
<th>Designation</th>
<th>Global Warming Potential, 100 yr</th>
<th>Atmospheric Life Time, yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-125</td>
<td>3400</td>
<td>29</td>
</tr>
<tr>
<td>HFC-23</td>
<td>12000</td>
<td>260</td>
</tr>
<tr>
<td>HFC-227ea</td>
<td>3500</td>
<td>33</td>
</tr>
<tr>
<td>HFC-236fa</td>
<td>9400</td>
<td>220</td>
</tr>
<tr>
<td>FK-5-1-12</td>
<td>1</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Other fire protection systems can be dealt with in a similar way, e.g. passive fire protection systems, automatic fire and alarm systems and smoke control systems.

4.3.3 PASSIVE FIRE PROTECTION

Passive fire protection is vital to the stability and integrity of a building or structure in case of fire. Passive fire protection with proven fire performance properties is built into the structure to provide stability and separate the building into areas of manageable risk that are designed to restrict the growth and spread of fire allowing the occupants to escape or the fire-fighters to carry out their activities. Such protection is either provided by the materials from which the building is constructed, or is added to the construction materials to enhance their fire resistance.

Recommendations for fire resistance are expressed in terms of time and the ability of dividing elements such as walls or floors to contain fire. Load bearing elements are required to maintain their capacity or integrity for the basic framework of the building, and include any element or service that provides an opening or passes through the walls or floor. It is vital that these protection measures are correctly designed, specified and installed if the building is to behave as expected should a fire occur. By their nature they are "passive" until there is a fire and only then will their fire performance in situ be demonstrated.

Built-in fire protection and passive fire protection

Most construction materials have some natural resistance to fire and as such comprise built-in fire protection.

This natural fire resistance may be enhanced by the use of added materials or components that are known by the collective term "Passive Fire Protection" (PFP). These are called passive because they do not need any special energisation or command signal to operate (although some systems such as dampers and certain types of doors may be designed to operate from such methods).
Passive fire protection includes:

- Cavity barriers.
- Ceiling systems.
- Compartment walls.
- Fire doors and building hardware (e.g. self-closing devices, latches etc).
- Fire resisting air transfer grilles (mechanical or intumescent).
- Fire resisting dampers (mechanical or intumescent) used in horizontal or vertical air distribution ducts.
- Fire resisting ducts.
- Fire resisting glazing.
- Fire resisting service ducts and shafts.
- Fire walls.
- Floors.
- Hinged or pivoted fire doorsets (timber or steel).
- Industrial fire shutters (rolling or folding).
- Linear gap seals.
- Sealing of pipe, cable and service penetrations of compartment walls and floors.
- Structural frame fire protection.
- Suspended ceilings.
- Membrane ceilings (horizontal partitions).
- The building envelope, e.g. fire resisting external walls, curtain walls, etc.

**Fire retardants**

Fire retardants are used primarily in furniture and fabrics and, as such, fall outside the scope of the Building Regulations. See also section 3.5. However, there are building products which, while not necessarily intended to be used for direct fire protection (such as those described above) are treated to ensure that they satisfy fire performance (reaction-to-fire) criteria recommended in AD B. Polystyrene, for example, may be treated with brominated flame retardants. Timber may have been treated with phosphorus-based products, though modern fire retardants should be more benign. These issues lie at the limits of this scoping study and have not been examined in any detail here, but will need to be kept under review.
4.3.4 FIRE DETECTION AND ALARM SYSTEMS

There are many types of fire alarm system, ranging from manual bells to aspiration detection systems. Modern electronics have dictated that most systems are now analogue addressable type. Nearly all fire alarm systems use dedicated wiring systems which are designed to continue to function at high temperatures.

- Smoke (optical). Most widely used. Detect scattering or absorption of light by smoke particles. This is generally used in most areas.

- Smoke (Ionization). Electric current flowing in an ionization chamber is reduced when smoke particles enter the chamber. Use tends to be less than optical because of problems associated with disposal of radioactive materials. Improved optical devices are supplanting this type of device. When such devices need to be disposed of they should either be returned to the original manufacturer or specialist advice sought.

- Smoke (optical beam). A beam is directed across a large area such as an atrium. In all other respects, works as optical device.

- Heat (fixed temperature). Activate when a pre-determined temperature is reached. Used in plant areas such as boiler rooms and kitchens, etc.

- Heat (rate of rise). Operate when temperature rises abnormally quickly. Used in plant areas such as boiler rooms and kitchens, etc.

- Flame detectors. Detect infra red or UV light emitted by fires. May be triggered by sunlight so need to be used with care.

- Fusible links. Used mainly in plant areas such as generator houses. A link in a wire is located above, say, a generator. If the melting temperature of the link is exceeded it melts and breaks the wire which in turn causes weighted valves and or mercury switches to operate, giving an alarm.

- High Sensitivity Smoke Detectors. HSSD systems are normally used in sensitive areas such as computer equipment rooms. They sample air via a tube and pass it over a very sensitive detector. This type of system needs specialist design installation and maintenance.

- Carbon monoxide detectors. Carbon monoxide detectors are being heavily promoted by some organisations as a "more reliable" form of device.

Alarm systems require electronic signal processing and alarm (communications) systems, which may be a control box in a single location, or repeated through the building. Larger buildings will have a control room.

4.3.5 SMOKE CONTROL SYSTEMS

Smoke control systems are used primarily to prevent, or limit, smoke spread onto escape routes. Some systems are passive, comprising openings, vents or shafts that allow smoke to dissipate. Extract systems may use vents that open on alarm. Other systems depend on powered extract or pressurisation. Powered extract depends upon a fan that is heat resistant, or protected from heat, to remove smoke, usually from a reservoir. Pressurisation uses a flow of air to increase pressures and hold back smoke from the
protected space. There are other types of system that combine the features of these. All
types of system require one or more fans or motors, actuation and control equipment, and
may require fixed or drop-down screens (e.g. fabric curtains) or opening make-up air
vents. They all require regular maintenance, but are essentially specialised air handling
equipment. Active systems all need to be actuated by a signal. The signal from a
detector will be needed to operate the system above. Alternatively, or in addition, the
system be operable by a manual triggering, e.g. from a control room.

4.3.6 WATER AND ENERGY USAGE OF ACTIVE SUPPRESSION SYSTEMS
In addition to an environmental ‘embodied energy’ cost associated with any active fire
suppression system there is the energy and water usage associated with ongoing system
maintenance (in compliance with the relevant standards and codes) which will also be
significant. These environmental impacts need to be considered balanced against the
potential benefits that active fire suppression systems can provide in the event of a fire.

The water associated with an active suppression system can be split into two categories, as
follows:

a  Stored water.
b  Discharged water.

Stored water may include water in a tank (or reservoir) and water in the system pipework.
The quantity of water needed for a system will be determined in accordance with the
relevant standards and codes. There is the potential for systems to be designed that
require less water and lower discharge densities than traditional sprinkler systems, for
example, fine water spray or water mist systems. These systems may reduce water
storage requirements significantly, perhaps by as much as about 80%. These systems
also benefit from other potential environmental savings compared to traditional sprinkler
systems; smaller pipes, less material, space, transportation required, etc.

For traditional sprinkler systems there is a significant amount of discharged water
associated with ongoing maintenance operations. Sprinkler system components that
require routine maintenance include fire pumps, alarm valves, flow switches, ball valves
and isolation valves. Information supplied to BRE [102] indicated the following water
usage for maintenance operations (assumed to be typical):

- Diesel fire pumps – 67,000 litres per annum.
- Electric fire pumps – 22,300 litres per annum.
- Alarm valves – 31,200 litres per annum.
- Flow switches (20 zones) – 25,600 litres per annum.
- Ball valves – 4,000 litres per annum.

Additionally isolation valves need to be tested every three years which require a ‘drain-
down’ of the system and associated significant water use.

As an example, for a ten-storey building it has been calculated that 275,000 litres of water
per annum could be used on maintaining a sprinkler system. Most of this water discharge
is potentially avoidable. Pump cooling water can be recycled; alarm valves, flow
switches, isolation and non-return valves can be tested with zero water waste. Ball valves and water tanks could potentially be maintained at reduced levels of water usage.

There is also significant energy use associated with maintaining a sprinkler system both directly and indirectly. Similarly to the use of water, there is also potential to reduce the amount of energy consumed in complying with the relevant standards and codes for maintenance. This could be in the form of smaller pumps, reduction in pumping capacity and frequency of operation and with the adoption of alternative or innovative techniques. A 40% to 75% possible reduction in energy savings is predicted.

Therefore it is possible, in comparison with traditional sprinkler system design, to:

- Reduce water storage.
- Significantly reduce water usage for maintenance operations.
- Reduce energy consumption.

Improving the sustainability of fire sprinkler systems could potentially be readily achievable.

4.4 The BRE environmental profiles methodology

Environmental Profiles provide standardised, reliable and independent information about building materials and components. Based on Life Cycle Assessment, they measure the environmental performance of materials and products over their entire lifecycle through their extraction, processing, construction, use and maintenance, and their eventual demolition and disposal. They provide information on 13 key issues related to environmental sustainability, such as climate change, ozone depletion, acidification, consumption of minerals and water, toxicity and the quantity of waste sent for disposal. (See also section 6.6).

BRE Global operates and manages an Environmental Profiles (environmental labelling) Certification Scheme producing Environmental Product Declarations. This scheme focuses on those materials and construction products with significant embodied environmental impacts and those for which credits are available in the following schemes: BREEAM, EcoHomes and the Code for Sustainable Homes [5, 99-101, 103, 104]. Within these schemes, credits are awarded for the use of specifications with low embodied environmental impact. The building elements that allow the achievement of credits and the schemes to which they are applicable are shown in Table 3.
### Table 3 – Types of building elements

<table>
<thead>
<tr>
<th>Elements</th>
<th>Non domestic schemes</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BREEAM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Offices - Design</td>
<td>PRY</td>
</tr>
<tr>
<td></td>
<td>Offices - Fitout</td>
<td>YYYY</td>
</tr>
<tr>
<td></td>
<td>Retail - Design</td>
<td>YY</td>
</tr>
<tr>
<td></td>
<td>Retail - Fit Out</td>
<td>YYYY</td>
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<tr>
<td></td>
<td>HEAT (WHS)</td>
<td>YYY</td>
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<td></td>
<td>Healthcare</td>
<td>YYY</td>
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<td></td>
<td>Prisons</td>
<td>YY</td>
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<td></td>
<td>Schools</td>
<td>YY</td>
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<tr>
<td></td>
<td>Courts</td>
<td>YY</td>
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<tr>
<td></td>
<td>Industrial</td>
<td>YY</td>
</tr>
<tr>
<td></td>
<td>EcoHomes</td>
<td>YY</td>
</tr>
<tr>
<td></td>
<td>Multi Residential</td>
<td>YY</td>
</tr>
<tr>
<td></td>
<td>Code for Sustainable</td>
<td>YY</td>
</tr>
<tr>
<td>Upper Floors</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Ground Floors</td>
<td></td>
<td></td>
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<tr>
<td>External Walls</td>
<td>Y</td>
<td>YY</td>
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<td>YYYY</td>
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<tr>
<td>Floor Finishes</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>Windows</td>
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<td>YY</td>
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<tr>
<td>Internal Walls/Partitions</td>
<td>Y</td>
<td>YY</td>
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<td>YYYY</td>
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<td></td>
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<td>YYYY</td>
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<tr>
<td>Suspended Ceiling Finish</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Hard Landscaping</td>
<td>Y</td>
<td>YY</td>
</tr>
<tr>
<td>Boundary Protection</td>
<td>Y</td>
<td>YY</td>
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<td></td>
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<td>YY</td>
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</tbody>
</table>

The impacts of construction materials and building components vary by orders of magnitude. To ensure the most significant environmental impacts are captured, the current methodology excludes finishes, fittings, services and minor elements, e.g.

- **Finishes**
  - paints
  - wallpaper
- **Fittings**
  - shower trays
  - taps
- **Services**
  - air conditioning units
  - plumbing and wiring
- **Minor elements**
  - stairways
  - doors

Further information on elements of fire protection systems is needed as input to the methodology, including:

- mass
- dimensions
- details of where the materials are sourced from
- composition

BRE may have relevant Life Cycle Assessment (LCA) datasets but, if not, these have to be obtained. The best approach may be to undertake a short desk top analysis to review what the actual requirements are.
4.5 Current relevant activities in CEN fire safety arena

CEN created a new committee - CEN BT WG 206 – CEN contribution to the EC lead market initiative on sustainable construction, in June 2008, at the request of the European Commission. The scope of this group is “to carry out an inventory of currently existing standards in order to identify possible needs for further contributions to the initiative”. In order to identify further needs it will be necessary to establish a strategic framework for the long term onto which the inventory of relevant current activities can be mapped.

The activity has now been divided into the Basic Works Requirements (BWRs) taken from the draft Construction Products Regulations. These are:

- BWR1 – Mechanical resistance and stability.
- BWR2 – Safety in case of fire.
- BWR3 – Hygiene, health and the environment.
- BWR4 – Safety in use.
- BWR5 – Protection against noise.
- BWR6 – Energy economy and heat retention.
- BWR7 – Sustainable use of natural resources.

The CEN Technical Committees with an interest in fire safety related matters are contributing to producing a road map on behalf of BWR2. Whilst some of the product Technical Committees are struggling to understand the sustainability issues, other stakeholders are considering this to be an opportunity to try to change some aspects of the current fire safety framework. It can be expected that this CEN activity will lead to the development of new standards for measuring specific characteristics and parameters that will be needed as part of the future sustainability assessments for products. It could also be the case that some of the established fire test methods will need to be revised or new tests methods developed to assess and characterise the modes of failure of the new generation of sustainable construction products that are currently emerging.
5 Specification for a cost benefit analysis tool

The specification for the development of a Cost Benefit Analysis (CBA) tool including environmental impact issues and covering all Approved Document B purpose groups was considered.

Even before environmental impacts are considered, there are assumptions made for the current tool which require further research to quantify and reduce the uncertainties. The CBA tool is sufficiently flexible to handle any environmental impact metric(s), e.g. tonnes of carbon dioxide (CO₂) produced, Ecopoints. However, it takes the consequences of each fire scenario as input, so another tool or technique would be required to evaluate these. The next stage is to convert environmental impacts to monetary terms. There is currently no general consensus on how this should be done. Some examples of environmental cost benefit studies conclude this section.

5.1 The current version of the cost benefit analysis tool

The current version of the Cost Benefit Analysis (CBA) tool was developed by BRE in support of BB 100 [105] for the design of fire safety in schools. It is intended for designers, architects, fire safety engineers or others who wish to assess the likely benefits in providing a range of fire safety measures in their building. If there is more than one building, the tool should be applied to each independently, although any savings (e.g. a common inspection and maintenance program for the whole site) should be accounted for.

The tool comprises a series of interlinked Excel spreadsheet pages. Its structure is represented in Figure 6. The bulk of the tool is made up from sheets defining the various risk scenarios. There are also sheets that define various protection systems, which interact with the scenarios in various ways to reduce the risk. The QRA (risk) module calculates all the risks, the CBA module calculates the costs and also other benefits (not related to risk reduction).

Figure 6 Diagram showing the structure of the QRA and CBA tool
This spreadsheet tool allows the user to look at the effects of various combinations of prevention and mitigation systems on various fire scenarios. It calculates:

i) the risk, converted to monetary terms, before and after the package of systems is in place

ii) the cost of supplying the package of systems

iii) the net difference between the benefit (i.e. reduced risk) and cost, and the probability (confidence level) that this net difference is positive

The probability that all the systems, modelled in the tool, fail to prevent a scenario (or reduce its consequences) is given by the product of all the individual probabilities. In other words, all the systems are assumed to act independently, which may not actually be the case in reality. The model does not currently handle conditional probabilities.

5.2 Assumptions in the risk/CBA tool

The risk and CBA tool contains a number of assumptions, which require further research in order to provide data and reduce uncertainties. This section deals with those assumptions which affect all fire risks, not just the environmental impacts.

Fires have four levels of severity, corresponding to confined to item first ignited/room of origin/area of building (or floor of origin), and catastrophic (building effectively totally destroyed). It is necessary to know what fire size gives rise to the greatest risk – smaller fires as a result of their greater likelihood, or larger fires as a result of greater consequences. If the latter, a less coarse definition at the large fire end is required (or simply acceptance that there will be very larger uncertainties).

The probability of ignition is assumed to be proportional to the number of rooms of a given type. However, there is no modification of this in the tool to account for variations in room area. Work by Ramachandran in the late 60's/early 70's [106] suggested $\text{pr(ign)} \propto A^{\frac{1}{2}}$ for the textile industry, for example. (In the tool, the assumption is $\text{pr(ign)} \propto A^0$). In order to determine this relationship, there are a couple of possibilities:

- The Fire and Rescue Service needs to routinely record an estimate of the room size. This is not done at present for the national UK fire statistics, although the databases of some Metropolitan Fire and Rescue Services do include this information [107].

- Examination of the cause of ignition as given in the UK fire statistics, coupled with assumptions how this is related to the room size. For example, in an industrial building the likelihood of ignition may be proportional to the amount of machinery, which in turn could depend on the area (or even the volume). Electrical fires may be proportional to the number of power sockets, which in turn could be proportional to the room perimeter, and hence lead to an $A^{\frac{1}{2}}$ relationship.

A further weakness in the above assumptions is that, although the number of fires may be estimated from the statistics, the number of rooms in which those fires could potentially occur is unknown. In fact in some occupancy types, even the number of buildings may be unknown. The approach used in the schools CBA [105] was to estimate the number of school pupils in the country; coupled with an estimate of the number of schools gives an average size. The BB 98 [108] and BB 99 [109] design guides gave suggested numbers of rooms for a given school size, which was then extrapolated based
on the average size. However, this level of data may not be available for other occupancies.

A possible solution to this difficulty could involve a sensitivity study where the parameter being varied is the total number of buildings in the UK stock. This analysis would enable a suitable threshold value to be determined, e.g. the maximum or minimum number of buildings required for protection measures to achieve “break even” at a given confidence level.

The spreadsheet does not include all room types that may possibly be present. However, it includes those where fires are commonest, so there would only be a problem if low-probability, high-consequence fires were overlooked.

Transition probabilities from one fire size to another can be estimated from the UK statistics, although this gets harder for bigger fires because the data are sparser. The effectiveness of various fire protection systems/ intervention strategies needs to be estimated as a function of fire size.

The consequences of fires (apart from deaths and injuries) are very uncertain. The UK statistics do not collect much useful data. Insurance statistics concentrate on the overall financial impact (and not all impacts are, or can be, claimed for).

5.3 Consideration of the inclusion of environmental impact issues in the CBA tool

In the current version of the CBA tool, the treatment of environmental impact and sustainability issues is handled very simply. The environmental consequences of different fire scenarios are estimated in terms of Ecopoints. The average UK citizen has an annual environmental impact defined as 100 Ecopoints. BRE Digest 446 [110] provides a full description of Ecopoints and how they can be applied.

For environmental consequences, a starting point is to know what has been burnt, and how much of it. Fire statistics [111] record the former (in generic terms) but no longer the latter (“AREABURN”, the area damaged by burning, was a very useful statistic but stopped being collected around 1999~2000). Surveys have estimated the total fire loads for different occupancies [112], which have been quoted in BS 7974 [113] inter alia). As the primary reference shows, these surveys may be out of date. However, given all the other inaccuracies that are likely to come into the calculation, this may not be too critical.

It might be useful to have a breakdown between the contributions of cellulosic and plastics to the overall fuel load as this may help to improve estimates of the mass of fuel consumed (because the heat release per kg is significantly different). A further complication is that, particularly in “fully-involved” fires, there is insufficient oxygen available for complete combustion. Thus for example fires produce C (soot) and CO as well as CO2. One solution could be the performance of full scale “room burns” to measure what is produced. This is likely to be hugely expensive, not only because full-scale tests always are, but also because a large number of species need to be monitored (not just CO and CO2). Of particular interest could be various “exotic” compounds that may only be present in trace quantities yet could still have significant environmental impacts.

All fires produce CO2 as a combustion product. A cellulosic fuel (wood, paper) produces 1.6 kg of CO2 for each kg of fuel consumed. For plastics, the ratio is nearer 3:1.
Just using the CO₂ release as a measure of impact may only capture a small fraction of the total (e.g. if “exotic” compounds are significant). Furthermore, since the daily production of man-made CO₂ is large, the impact of fire will appear relatively small. An average person produces 12,300 kg CO₂ (equivalent) per year, which constitutes (according to the definition) 35% of their overall impact (i.e. 35 Ecopoints). Each kg of CO₂ is therefore equivalent to 0.0029 Ecopoints. It has been estimated that the total CO₂ production of all fires in the UK is roughly equivalent to the normal output from a small town (10,000 people) [114].

It is noteworthy that, despite initial concerns, less is heard in the media about the environmental impacts of the Buncefield fire [115] (the largest fire/explosion since the Second World War) than is heard every time an oil tanker runs aground, for example. This may be because the impacts of the fire (once the smoke has dispersed) are less obvious – e.g. the release associated with refurbishing the damaged surrounding buildings is invisible and therefore not newsworthy.

A recent report [116] estimated the whole-life “cost” in terms of CO₂ production for a typical office building was only increased by 1-2% when fires were taken into account. With such a low figure, it is wondered whether there is any point worrying about it. It might be that there are only a few occupancy classes (e.g. industrial/warehouse) where the risks are high enough to justify consideration of environmental impacts.

Whilst fire protection systems and procedures would be expected to reduce accidental environmental damage arising from fires, their provision will also entail some impact on the environment and sustainability, e.g. raw materials and energy for manufacture, waste products from manufacture, energy for operation. The CBA tool does not consider such factors (only the monetary cost of supply and maintenance), and would therefore need to be extended in these areas.

5.4 Assigning monetary value to environmental impacts

From reading the literature [117-126], it is apparent that the design of the CBA tool is secondary to issues of assigning monetary values to environmental impacts.

Is it essential to express values in monetary terms? In multi criteria decision analysis, the multiple criteria are typically reduced to a single one by using different weightings for each term.

\[ V = \sum_{i=1}^{n} \lambda_i v_i(z_i) \]

Each indicator \((z_i)\) is normally given a value \(v_i(z_i)\) that is normalised between 0 and 1. Then these values are multiplied by different weights \(\lambda_i\) to reflect their importance. Therefore, the multiple criteria have been reduced to a single overall value \(V\) which also has a normalised value between 0 and 1.

In theory, if it is possible to assign monetary cost to one component, then by using the different weightings from a multiple criteria analysis, it is then possible to assign costs to everything. However, since there will be considerable uncertainty in what the appropriate weightings are, there will also be even more uncertainty in what the overall costing will be.
The triangle tool developed by Hofstetter et al [119] is one possible approach to achieving a consensus on what the weighting values might be, see Figure 7a). Using the tool, it is possible to draw what is termed a line of indifference that divides two products from one another, see Figure 7b). Thus, this line of indifference defines the weighting factors for which product A is favourable to product B, and vice versa.

Figure 7a) the “triangle tool” 7b) illustrating the “line of indifference”
(Taken from [119])

One estimate [127] that the value of preventing one Ecopoint worth of environmental damage is about £50 although the uncertainty associated with this figure is very large, range ~£0 to ~£150.

A contrary view [128] is that monetary values cannot be applied to environmental damage, neither in terms of £’s per Ecopoint, nor in terms of the individual components. This view would require the thirteen individual components of the Ecopoint score to be evaluated independently, but does not offer any way of combining or comparing the relative importance. This is an unsatisfactory situation, and further work should therefore explore means by which monetary conversions (i.e. willingness-to-pay (WTP) figures) can be established.

Ecopoints are intended to represent a consensus between industry experts, regarding the relative importance of an average person’s different environmental impacts. It would therefore appear logical that, given an overall WTP figure can be assigned to the total impact, the WTP figures for the individual components would be in the same proportions as the weightings for the impacts used to calculate the Ecopoints. Reversing the calculation, if a WTP figure can be assigned to an individual component, this could then be scaled up to give a value for an Ecopoint.

For example, the UK Treasury value assigned to 1 tonne of CO₂ (for carbon trading purposes) is approximately £25 [129, 130]. The average person’s annual CO₂ production is 12.3 tonnes, which accounts for 35 of their 100 Ecopoints of overall environmental impact. Thus these figures suggest one Ecopoint would be valued at approximately £9. Compare this to the estimate above to see some idea of the uncertainties that will arise.

As discussed earlier in section 5.3, the CO₂ produced in fires is relatively small compared with people’s daily production of man made CO₂. Therefore, the environmental impact of most fires, based solely on their CO₂ release, will be very small.
A further difficulty in assigning monetary values to environmental impacts arises from the different range of accounting systems available. In all company operations, there are two versions of accounting that are widely used. The first of these is cost (or management) accounting, which is used to determine production costs and set the selling price. There is also financial accounting, which is used to provide profit and loss information for shareholders. Financial accounting is standardised and well regulated.

Some companies have taken to using environmental management accounting [125]. This includes physical metrics for energy and material flows, and monetary metrics for costs, savings and revenues related to activity with potential environmental impacts. However, since there is no standard definition of environmental costs, the calculations may be distorted.

The cost categories in environmental management accounting include: the waste disposal and emission treatment; the costs of prevention of damage and environmental management; the purchase value of material that is wasted; and the production costs of output that does not form part of the ultimate product. Note that social costs and external costs are not included in environmental management accounting. This form of accounting was developed for the company's internal decision-making.

Going one stage further, there is full cost accounting [124, 126]. The European Commission wants "consumption and use of environmental resources accounted for as part of the full cost of production, and reflected in market prices".

Normally, decisions are made which do not reflect public, or other private, costs which are not borne by the decision-maker. These costs are known as external costs. It is the role of full cost accounting to determine what these external costs are.

Full cost accounting has not really caught on yet, because there is a widespread belief that conversion to monetary terms is either "too costly" or "too difficult" to implement. The amount of data required is extensive. One of the first steps is to ensure that the modelling of environmental impacts is robust. Some methods include calculating the eco balance, which is the net input or output of materials, for an organisation is a whole; life cycle analysis, which is similar to the eco balance, but for a particular product or activity; and the ecological footprint, which is usually calculated on a country-wide basis.

In addition to the range of different tools that may be used to measure the impacts, there is no clear consensus on which methods to use for costing the use of resources. One option is to calculate the cost of prevention. For this, it is necessary to define the level of emissions, determine how the prevention of emission may be achieved, and then work out the cost of doing this.

Another option is to calculate the cost of environmental damage directly. For this it is necessary to assess the physical impact, and then estimate the economic damage resulting from this impact. There is a further subdivision with four ways of doing this:

- Existing prices (e.g. health costs for medical treatment also including loss of earnings while off work).
- Cost of transport (e.g. how much people would be prepared to pay to visit a similar amenity to that damaged).
- Economic pricing (e.g. house prices reflect being in a "nice" area).
• Contingent valuation (willingness to pay to prevent and environmental impact, or willingness to receive, in other words to accept in environmental impact). This method would be consistent with the Treasury approach of using willingness to pay values for such things as the value of a life.

• Alternatively, some methods use the cost to prevent a given level of damage (Dutch system).

One of the questions for full cost accounting to consider is how wide the boundaries should be set. For example, should they simply consider the company operations, or should they also consider the materials and energy cost involved in implementing systems to prevent environmental damage.

The full cost of environmental goods and services, such as raw materials, clean air and water, needs to be known in order for full cost accounting to be applied.

Agreement on the costs of environmental impacts is still a considerable way off. At present, there is not even a standard terminology. It would not be sensible to define a method for the CBA of the environmental impacts of fire, only to find no agreement with anyone else. It is clear that the CBA tool must be capable of handling uncertainties, which may have a very large magnitude. In one recent attempt [122] to apply full cost accounting, the variation in value spanned a range of 1 to 10,000.

5.5 Relevant international studies

5.5.1 FM GLOBAL, USA STUDY


This study focused on carbon emissions, adding the contribution from fire and natural hazards to those arising from normal operating conditions. It concluded that, without effective fire protection systems, the risk of fire increased the carbon emissions by 30~40 kg CO₂ per m² of floor area (an increase of 1~2% over the normal lifetime) for a standard office building, and by up to 14% for a facility exposed to extensive fire hazards. By way of comparison, wind hazards in the east and gulf states of the United States increased the carbon emissions by 30~40 kg CO₂ per m² of floor area (an increase of 1~2% over the normal lifetime) of a typical industrial building. As buildings are designed for increased sustainability (e.g. by improving energy efficiency) then the relative importance of these risk-based contributions increases.

The total carbon emission over the lifetime of a building included one-off events such as construction and decommissioning, and regular emissions arising from maintenance and operation (the contribution was given simply by the annual emission rate multiplied by the expected building lifetime in years). Energy consumption was considered implicitly by its contributions to carbon emissions, using current energy production techniques. This was the dominant source of emissions associated with normal operations, and the rates were calculated by following standard guidance (e.g. their ref [131]). About 80% of the emission arose from normal operation, with the remaining 20% “embodied” in the production of the construction materials, etc.
The carbon emissions from fire per unit area of the building were given by the following equation:

\[
CE_{fire} = f \cdot L \cdot \left( F_b \cdot m^* \cdot \varepsilon_{CO2} + F_r \cdot CE_{emb} \right)
\]

where \( f \) is the annual frequency of fires, \( L \) is the building lifetime, \( F_b \) is the fraction of the fuel load burned, \( m^* \) is the fuel load (\( \text{kg/m}^2 \)), \( \varepsilon_{CO2} \) is the yield of \( \text{CO}_2 \) (\( \text{kg/kg fuel} \)), \( F_r \) is the fraction of material replaced during reconstruction, and \( CE_{emb} \) is the "embodied" carbon per \( \text{m}^2 \) of the building area.

Variations with building height were neglected.

The paper supplied some values for the parameters in the equation. Thus, for a current standard office building ("case 1" in the paper), \( f \) is 0.001 large fires/year, \( L \) is 40~60 years, \( F_b \) is 0.5~0.8, \( m^* \) is 38~115 \( \text{kg/m}^2 \), \( \varepsilon_{CO2} \) is 3.0 \( \text{kg CO}_2/\text{kg fuel} \) (i.e. primarily plastic polymers rather than cellulosic), \( F_r \) is 0.8~1.0, and \( CE_{emb} \) is 0.15~0.2 multiplied by the total carbon emission per \( \text{m}^2 \) of the building area (3,300~4,500 \( \text{kg CO}_2/\text{m}^2 \)). In the above, a large fire is defined as one causing losses in excess of US$1m.

Although references are supplied for all these values, some of them intuitively seem a bit high (particularly \( f \), \( F_b \) and \( F_r \)).

5.5.2 APPRAISAL OF FM GLOBAL RESEARCH STUDY WITH DATA FROM THE UK

Examination of the UK fire statistics for 1998 [111] (the last year in which AREABURN data was reliably collected), reveals that there were approximately 1,500 office fires (of all sizes) recorded by the fire brigades, with an average area burnt of 7.15 \( \text{m}^2 \). The contributions of fires of different sizes to the total area burnt are shown in Figure 8.

![Figure 8 Contributions of fires of different sizes to the total area burnt](image-url)
If a “large” fire is defined as one in excess of 100 m², there were 16 of these (estimated), with an average area damage of 365 m².

A rough estimate of the risk of fire in UK offices can be made as follows. Suppose that there are, out of a total working population of 29.2 m, maybe 10m~20m office workers. With a further estimate of 100~500 staff per office block, there would be 20,000 ~200,000 office buildings (even more if the average size is smaller). The UK annual risk of “large” fires is therefore between 16/20,000 and 16/200,000, which is between 1 and 10 times smaller than the US estimate.

If it is assumed that $m$” is 38~115 kg/m², $\varepsilon_{CO2}$ is 3.0 kg CO₂/kg fuel, as in the US study, then the total mass of CO₂ emitted by the 16 “large” fires in 1998 was between $6.8 \times 10^5$ ~ $2.1 \times 10^6$ kg. If it is further assumed that an average office worker occupies 10 m² of floor area, then 10m~20m workers require between $1 \times 10^8$ ~ $2 \times 10^8$ m². The amount of CO₂ (released by large office fires in one year) is therefore between 0.0034 and 0.021 kg/m². Over the lifetime of the building, this would be approx 0.01 ~ 0.1 kg/m².

Note that this calculation has not accounted for the “embodied” CO₂ lost due to refurbishment. Supposing that these 16 fires require a complete demolition and rebuild, and taking the embodied CO₂ as 675 kg/m², the loss over a building lifetime (30~40 years) will be approximately $(30~40) \times (16/20,000 ~ 16/200,000) \times 675 = 1.6 ~ 21 $ kg/m².

For comparison, the US figures in Equation 1 give, for the building lifetime:

$$CE_{fire} = 0.001 \times (30~40) \times \{ (0.5~0.8) \times (38~115) \times 3 \ + \ (0.8~1) \times 675 \} \ kg/m^2$$

i.e. $$CE_{fire} = 0.001 \times (30~40) \times \{ (57~276)+ (540~ 675) \} \ kg/m^2$$

i.e. $$CE_{fire} = 18~38 \ kg/m^2$$

For this analysis it is concluded that:

- The “embodied” CO₂ may be the dominant component.
- The US estimate of the carbon emissions is somewhat higher than one would make for the UK (maybe an order of magnitude higher).

### 5.5.3 BRANZ STUDY, NEW ZEALAND

Some research carried out by BRANZ in New Zealand [132, 133] has included environmental impacts in the cost benefit analysis to show the effectiveness of domestic sprinkler systems. In this analysis, no monetary value was assigned to environmental impact. Instead, this impact was expressed in terms of NZ Ecopoints. Various installation options were considered, and the number of NZ Ecopoints expended to save the human life was calculated. It was shown in each case that the net expenditure of NZ Ecopoints was positive, in other words, the reduction of fire damage due to the sprinklers was greater than the environmental impact of their manufacture and installation.

Relevant conclusions from the New Zealand study were:

- “Sustainability aspects associated with home sprinklers and structure fires were successfully incorporated into the cost effectiveness analysis for home sprinkler systems in terms of a module for environmental impact.
• The use of a Life Cycle Assessment approach allowed a wide range of environmental impacts to be considered and for a single representative measurement to be used in conjunction with the monetary based cost effectiveness analysis of the impact of home sprinkler systems.

• This study represents the first use in New Zealand of Ecopoints for the quantitative metric for environmental impact, which is currently commonplace in the UK and elsewhere.

• The results for all scenarios indicated that a saving of NZ Ecopoints would be made for each life saved with the inclusion of home sprinklers in New Zealand residential properties. That is, for the monetary cost associated with each life saved, a net positive impact for the sustainability aspects, in terms of the environmental issues, considered was also achieved.

• The model results for the impact of home sprinkler systems for the base case, considering sprinklers and smoke detectors present, indicate a range of mean environmental benefits per life saved of approximately 11 to 170 equivalent years of average environmental impact of a New Zealander (i.e., 1,100 to 17,000 NZ Ecopoints) depending on the category of residential building stock occupier.

• The results for environmental impact benefits per life saved were presented as distributions to account for input parameter uncertainty (e.g. for the base case, considering sprinklers and smoke alarms present).

• The approach to incorporating sustainability aspects into this model only considered the environmental issues for the cradle to grave impact for sprinkler systems and loss and replacement of flame damaged building stock, i.e. the environmental impacts related effects of fire and the loss and replacement of home contents were not included in the assessment. It is expected that the inclusion of these additional aspects would produce an even more positive contribution to the measure of environmental benefits.

• The use of NZ Ecopoints to provide a measure of a wide range of environmental impacts allows broader sustainability aspects to be incorporated into current cost effectiveness analyses, with the opportunity for direct comparison as monetary estimates are proposed in the future.

• Incorporation of sustainability aspects into the cost effectiveness analysis for home sprinkler systems provides a broader insight into the overall costs and benefits, including aspects that currently have no monetary equivalent.

Areas of future work that were recommended in the New Zealand study included:

• Expansion of the environmental impact module to include the effects of fire and the loss and replacement of home contents.

• Estimation of a monetary value to be applied to NZ Ecopoints, similar to the approach of a Value of a Statistical Life estimated for a life saved.
• Expansion of the concept of the incorporation of the environmental impact module complementing a cost-benefit analysis to include broader sustainability issues, which cover environmental, economic and social aspects.

• Identification of other potential categories of residential properties for which home sprinklers may be of particular benefit. E.g. Residences in rural areas, because of the potential extra time delay in fire service (which may be solely volunteer based in some areas) arrival at the scene and potential water supply problems. In addition, a house fire in a rural or remote surrounds would be more likely to be adjacent to ecologically sensitive areas. Therefore the less water used in a sprinkler system the less soil and aquatic contamination in combination with a smaller fire in total and the environmental damage associated with that.” [133].

5.5.4 UNIVERSITY OF LUND STUDY, SWEDEN
In 2008, a Masters thesis was published on work carried out by Lund University of Technology [134] on Climate conscious fire protection engineering - a life cycle method for assessing greenhouse gas emissions. Apart from the abstract, the full thesis appears to currently only be available in Swedish.

“The purpose of the thesis is to show how greenhouse gas emissions from fire protection solutions can be quantified in a life cycle perspective. An additional purpose is to investigate if and how the result can be interpreted in order to be used as a decision criterion for fire protection planning. The result is a method for assessing and comparing greenhouse gas emissions from different fire protection solutions in a life cycle perspective. The method is developed alongside with a social planning example case. The results show that the method is fully practicable when data of satisfying quality can be obtained. However, high quality data is not always available, and it may also be difficult to know what materials and technical solutions will be used to fulfil the functional requirements set up in the fire protection planning stage. Therefore an important focus area of the study is how to improve and interpret uncertain data. Conclusions are that the developed method can be used to quantify and compare fire protection solutions greenhouse gas emissions. There is good potential for the fire protection industry to lower its greenhouse gas emissions”. [134]
6  Inclusion of fire safety in environmental/sustainability tools

Relevant environment/sustainability tools were identified and the inclusion of fire safety/protection scoring in them was scoped.

6.1  Existing environmental and sustainability tools

Sustainability is normally described using the Brundtland definition, ‘meeting the needs of the present without compromising the ability of future generations to meet their own needs’ [136].

BRE’s report, Sustainability in the Built Environment: An introduction to its definition and measurement [137], sets out much of the background to the interpretation of sustainability in the context of the built environment, and the types of assessment tools which are commonly used within the UK.

Existing Environmental and Sustainability tools can be characterised into three types.

6.1.1  TYPE 1: OVERALL BUILDING ASSESSMENT METHODS

Type 1 tools: Overall Building Assessment Methods, such as BREEAM [138] and the Code for Sustainable Homes [5]. These tools use a series of indicators or other tools, to assign credits to a building to rate different aspects of its sustainability, e.g. energy use, materials used, water used, health and well being. They are used by a number of users, e.g. building owners, developers and planning authorities to assess the sustainability of various schemes. The tools are generally not prescriptive, so there are many different ways of achieving a particular level – the tool does not set out the route to do this. For BREEAM and the Code for Sustainable Homes, most of the indicators used are environmental in nature, with very limited social indicators and no economic indicators.

Figure 9 shows how the different impact areas are assessed through credits, which are then weighted and added to give an overall building score.
6.1.2 TYPE 2: DETAILED DESIGN TOOLS - BUILDING ENVIRONMENTAL MODELLING SOFTWARE

Type 2 tools: Detailed Design tools - building environmental modelling software, such as Autocad’s Ecotect [139] or IES VE-ware [140] or Envest2 [100]. These tools normally cover a specific environmental or sustainability aspect or are a series of linked tools each examining a single aspect, and allow the user, normally the designer, to assess different options in terms of a number of performance criteria. They are intended to work with a complex model of the building, at detailed design stage, to model sophisticated changes to the design although some can also be used at earlier stages of the design. They can cover, for example, daylighting, thermal modelling, acoustics, wind modelling, embodied impact and some may have some fire related aspect, for example regarding evaluation of escape from fire. A number of the tools, such as Ecotect or IES-Virtual Environment, allow the same building model to be evaluated for a number of different environmental aspects.

6.1.3 TYPE 3: EARLY DESIGN TOOLS

Type 3 tools: Early Design tools – e.g. IES for Google Sketchup [141], Ecotect, Envest2 and BRE’s Green Guide Online [103]. These tools again normally cover a specific environmental aspect, and allow the user to evaluate simple building shapes or changes in design or construction materials.

6.2 Inclusion of fire safety within Type 1 (Building Assessment) tools

The inclusion of fire safety within Type 1 tools such as BREEAM or the Code for Sustainable Homes would need to be on the basis of a perceived importance for the issue in terms of environment or sustainability as this is the basis for the development of the credit structure.

The possible aspects which could be included within such tools are:
a) the environmental impact of providing fire safety systems (in terms of materials and energy used to provide and operate them);

b) the benefits such systems provided in terms of increased safety or reduced risk;

c) the possible impact of an actual fire incident in terms of social, economic and environmental issues. (This could be based on the CBA tool described in section 5, alongside some indication of the likely risk of a fire over the building life).

Taking these three aspects in turn, the following considerations are relevant:

a) Embodied and operational impact of fire protection systems

i) Are these impacts significant in comparison to the impacts of other building materials or services? Some approaches, for example the protection of structure or escape routes using fire retarding materials, may already be included within materials assessments whereas other approaches, such as sprinkler systems may currently be ignored. Some systems may require minimum materials input, but an ongoing active energy requirement, whilst others may require considerable materials input but a passive operational input.

ii) Ensuring that the different systems are fairly compared within the existing tools is important and it is possible that as the mechanisms for the evaluation of materials within BREEAM and the Code at the moment only deal with building fabric, and energy credits do not consider operation of fire safety systems, then passive solutions may be in some way penalised in comparison to active systems.

iii) At present knowledge of the relative embodied impact (impact of extracting, manufacturing, transporting and disposing of materials) of fire protection systems to building fabric is very small, and this is an area where more work is required before its importance can be understood. The importance of the operational impact of fire safety systems is also not well understood.

b) Benefits of different fire safety approaches

i) How different are the possible benefits of different fire safety approaches and is the regulatory minimum already at a high standard? Tools such as BREEAM and the Code only reward those schemes which are in advance of regulatory minima (see Figure 10).
Environmental Standards

Figure 10 Diagram showing relevance of BREEAM with regard to regulation

ii) What are the incentives to the construction industry to demonstrate increased levels of fire safety (relative to Approved Document B)?

iii) It should be noted that BREEAM In Use [142] does cover aspects of building management, and therefore well maintained fire protection systems should achieve greater levels of credits. (See section 6.5).

iv) Why should higher levels of fire safety be relevant to any environmental impact tool?

c) Impact of fire incident

i) How high is the risk of a fire and how important is the impact of a fire incident when it occurs in comparison to the impact of the building overall, and the fire safety measures used to address it?

ii) How different are the possible options in terms of environmental impact? The cost of fire damage and rebuilding is already known, relative to the cost of the building, and is not currently seen as a relevant aspect for inclusion within BREEAM or the underlying life cycle assessment method which determines materials credits. The environmental impact of a fire, in terms of greenhouse gases, pollutants etc must therefore be both potentially significant and reasonably likely to make it relevant to include within building assessment tools as a possible indicator. Within BREEAM, aspects of material use are considered using the Green Guide and this is further discussed in the section covering early design tools below. Figure 3 illustrates how a fire incident can have impact on the environment, from release of emissions to air, water and land and from the generation of waste, and from the use of materials to extinguish the fire.
6.3 Inclusion of fire safety within Type 2 (Detailed Design) tools

In terms of Type 2 tools, detailed design tools, the inclusion of the environmental impacts of fire safety will depend on the tool type. Most Type 2 tools are dealing with a specific aspect, e.g. lighting or ventilation design, and fire safety has no direct relevance. The tools where fire safety will be directly relevant are those tools which deal with the impact of materials, such as the Envest2 and the Green Guide. However, some tools, such as IES VE-ware already provide tools looking at building evacuation and egress [143]. There may be opportunities to develop modules for other aspects of fire safety for these types of tools to encourage designers to consider them alongside other aspects of environmental impact.

The Envest2 tool provides whole building level analysis of the building materials used for both the building structure and fabric and building services, and the operational impact of the building. The assessment of building materials is based on Life Cycle Assessment, using BRE’s Environmental Profiles Methodology [144], which was developed in consultation with industry. Figure 11 shows the types of environmental aspects which are normally included within Life Cycle Assessment of a building.

![Figure 11 Schematic showing what is included within Life Cycle Assessment of a building](image)

Alongside environmental impact, financial costs, including Whole Life Costing are also provided within Envest2. At present, the building services included are just based on materials for heating, cooling and ventilation, and lifts, and are based on very basic rules of thumb, and for operation, benchmarks for operational energy from ECON 19 are used. It would be appropriate for a much wider range of services, including fire detection and suppression systems to be included within the Envest2 model, covering both embodied impacts and a more detailed evaluation of the operational impacts. Figure 4 shows the component parts of a sprinkler system for example which would be included within an embodied impact assessment of a system. However, the complexity of modelling within
Envest2 would mean that the tool would be able to do no more than include the embodied and operational impact of different active fire safety strategies, with passive fire safety strategies being considered within the existing tool in terms of the amount of materials and building design used. The tool would not be able to, for example, model the effect of different strategies on an actual fire incident.

6.4 Inclusion of fire safety within Type 3 (Early Design) tools

As many of the detailed design tools can also be used at early design stage, then many of the comments above apply. With regard to tools specifically intended at early design stage, the Green Guide to Specification is the most relevant.

The Green Guide to Specification tool provides an environmental rating for different construction specifications, grouped into basic building elements (walls, roofs, floors etc).

Table 4 shows which Green Guide Element Ratings are used within which BREEAM schemes, and the Code for Sustainable Homes.

**Table 4 Green Guide Element Ratings used within BREEAM Schemes and the Code for Sustainable Homes**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Non-domestic schemes</th>
<th>Domestic schemes</th>
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<tbody>
<tr>
<td></td>
<td>BREEAM</td>
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<td></td>
<td>Bespoke</td>
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<td></td>
<td>Offices – Design</td>
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<td></td>
<td>Offices – Fitout</td>
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<td></td>
<td>Retail – Design</td>
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<tr>
<td></td>
<td>Retail - Fit Out</td>
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<td>NEAT (NHS)</td>
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<td>Healthcare</td>
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<td>Further Education</td>
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<td>EcoHomes</td>
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<td></td>
<td>Multi-Residential</td>
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<td></td>
<td>Code for Sustainable</td>
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<tr>
<td>Upper Floors</td>
<td>Y Y Y Y Y Y Y Y Y Y</td>
<td></td>
</tr>
<tr>
<td>Ground Floors</td>
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<td></td>
</tr>
<tr>
<td>External Walls</td>
<td>Y Y Y Y Y Y Y Y Y Y</td>
<td></td>
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<tr>
<td>Roofs</td>
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<tr>
<td>Floor Finishes</td>
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<tr>
<td>Windows</td>
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<tr>
<td>Internal Walls/Partitions</td>
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<tr>
<td>Insulation</td>
<td>Y Y Y Y Y Y Y Y Y Y</td>
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<tr>
<td>Hard Landscaping</td>
<td>Y Y Y Y Y Y Y Y Y Y</td>
<td></td>
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<tr>
<td>Boundary Protection</td>
<td>Y Y Y Y Y Y Y Y Y Y</td>
<td></td>
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</tbody>
</table>

Again, it is based on BRE’s Environmental Profiles life cycle assessment methodology. The Green Guide currently does not cover any aspect of building services. However, it uses the concept of a “functional unit” for the assessment of elements, so it would
potentially be possible for services, such as fire detection or suppression to be considered in terms of a given function, and for different options to provide the function to be compared using the Green Guide. Where functionality is difficult to describe, or the number of options is very limited, then this approach is of less value.

Another aspect which could be considered within the Green Guide with regard to fire safety would be the comparison of wall, ceiling or door options providing a given amount of resistance. Additionally, assessment of different types of fire escape may be possible.

However, it is unlikely, unless the impact of a particular aspect of fire safety has very high impact, that these Green Guide ratings will be incorporated into the Materials Credits structure of BREEAM or the Code for Sustainable Homes. The Green Guide which is used to award credits for materials use within BREEAM and the Code, currently takes into account the likely refurbishment and replacement of materials, and their disposal at end of life in landfill, incineration or recycling. The Green Guide could also take into account the impact of fire on the materials, and their replacement on the basis of likelihood – but only if the likelihood of fire in a building over the 60 year life is reasonably high, and the likelihood of a particular part of the building being damaged again significant, would this impact be significant enough to have an impact on the results. At present, BREEAM and the Code only have between 4% and 5% of credits available for the specification of key building elements with good Green Guide ratings. For additional building elements to be included within the credit structure, they must have comparable impact to the key building elements (floors, roof, external walls, windows and internal walls). Elements such as doors, fire escapes or ceilings are unlikely to have significant impact within the overall building, due to their low impact per unit, or small number of units within the building.

6.5 BREEAM In-Use

As mentioned above, currently, fire safety and fire protection are not included in most BREEAM schemes since most BREEAM schemes assess new buildings and the BREEAM assessment takes for granted that the building will satisfy the Building Regulations; the BREEAM assessment relates to additional sustainability features.

Existing buildings will not necessarily satisfy the current Building Regulations. BREEAM In-Use [142] is a new BRE scheme to help building managers reduce the running costs and improve the environmental performance of existing buildings. It consists of a standard, an easy-to-use tool and a third party certification process that provides a clear and credible route map to improving sustainability.

The BREEAM In-Use (BIU) scheme has three parts covering:

- Asset performance - the inherent performance characteristics of the building based on its built form, construction and services.
- Building management performance - the management policies, procedures and practices related to the operation of the building; the consumption of key resources such as energy, water and other consumables; and environmental impacts such as carbon and waste generation.
• Organisational effectiveness - the understanding and implementation of management policies, procedures and practices; staff engagement; and delivery of key outputs.

A further important feature of the scheme is an easy-to-use online tool to enable users to self-assess their buildings or portfolio of buildings and the operations within them.

BIU assesses the performance of non-domestic commercial, industrial, retail and institutional buildings in the following areas:

• Management: overall management policy, commissioning site management and procedural issues.

• Energy use: operational energy and CO₂ issues plus DEC, EPC and EMS.

• Health and well-being: indoor and external issues affecting health and well-being.

• Life safety, property protection and false alarm management – which includes fire safety.

• Pollution: air and water pollution issues.

• Transport: transport-related CO₂ and location-related factors such as staff travel.

• Ecology: ecological value conservation and enhancement of the site.

Credits are awarded in each area according to performance. A set of environmental weightings then enables the credits to be aggregated to produce a single overall score. The building is then rated on a scale of: Unclassified, ACCEPTABLE, PASS, GOOD, VERY GOOD, EXCELLENT or OUTSTANDING.

Assessment considers the core activities related to the building fabric and services. This allows buildings of any age to be compared across the range of issues to give a consistent approach. This provides a valuable tool for the property portfolio manager. In addition, management and operation is assessed to provide occupants and owners with an independent audit of the way the building is managed.

Fire protection/resilience is part of BIU.

Below are the fire-related questions in the latest version of BREEAM In-Use.

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Has a fire safety risk assessment been undertaken?</td>
</tr>
<tr>
<td>23</td>
<td>Is the fire safety risk assessment regularly reviewed?</td>
</tr>
<tr>
<td>24</td>
<td>Does the emergency plan take account of the environmental risks associated with fire incidents?</td>
</tr>
<tr>
<td>25</td>
<td>Does the emergency plan include strategies for protection of building and contents?</td>
</tr>
<tr>
<td>26</td>
<td>Have the fire service been involved in the development of the emergency plan?</td>
</tr>
</tbody>
</table>
It will be noted that these all relate to fire risk reduction since it is deemed self-evident that an actual fire must have a negative environmental impact and that risk-reduction measures must, consequently, be beneficial. The presence or otherwise of fire protection systems (passive or active) are not included since the overall sustainability benefits/disbenefits of any materials, hardware or other manufactured systems are necessarily unknown – hence this CLG project.

6.6 Weightings for BREEAM schemes

The weightings for BREEAM schemes consist of the following:

- An area weighting (where more than one function is present in the building). For example if the daylighting credit is achieved within the office areas of a building but not the retail spaces, the credit will be weighted according to the ratio of these areas, i.e. if the office space is twice the area of the retail space the credit will be worth twice as much in the office area as in the retail space.

- A section (or category) weighting. The credits within each section are summed together and weighted according to the section weighting, as with all BREEAM schemes. These section weightings vary according to geographical regions and are determined as follows.

6.7 Derivation of the BREEAM category weightings

6.7.1 BACKGROUND

All assessment methods of this type are weighted either through the implied weightings given by individual credits or by determining an explicit category weighting, as with BREEAM. Below is the process undertaken to obtain the BREEAM category weightings. Whilst the underlying data is real and obtained using statistical analysis, some subjectivity is used in translating the weightings to a local context. The subjective parts of the process have used expert advice and knowledge from experienced consultants in the field of building construction and building use. This approach is therefore the most appropriate and robust approach that exists in this field at this time. The weighting system is constantly under review. If more robust approach is forthcoming in the future, BRE are willing and able to review the approach and adopt changes where these are deemed to be more robust and appropriate than the current method. (See [110, 145-147]).

6.7.2 APPROACH

The methodology for deriving/updating the BREEAM non-domestic weightings has been completed using three stages.

- Stage 1: Quantification of the annual impact of UK non-domestic buildings.
- Stage 2: Establish relative impact of each category.
- Stage 3: Factors.

Stage 1: Quantification of the annual impact of UK non-domestic buildings

1a. UK non domestic building stock, annual data
Data from the UK non domestic building stock were examined and the annual impacts were quantified for the following BREEAM categories:

- Materials.
- Energy consumption.
- Transport.
- Waste.
- Water consumption.

Note: The remaining BREEAM categories (Management, Health and Wellbeing Land Use and Ecology, Pollution) are considered separately and will be discussed later.

1b. Environmental impact categories identified

As a separate study a series of 13 key environmental impact categories were identified as part of a Life Cycle Analysis (LCA) methodology (see Table 5) and independently weighted at the European level by a panel of environmental experts.

Table 5 List of key environmental impact categories

<table>
<thead>
<tr>
<th>Environmental Impact Category</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>21.64</td>
</tr>
<tr>
<td>Water Extraction</td>
<td>11.66</td>
</tr>
<tr>
<td>Minerals Resource Depletion</td>
<td>9.83</td>
</tr>
<tr>
<td>Stratospheric Ozone Depletion</td>
<td>9.13</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>8.64</td>
</tr>
<tr>
<td>Ecotoxicity to Fresh Water</td>
<td>8.59</td>
</tr>
<tr>
<td>Nuclear Waste</td>
<td>8.24</td>
</tr>
<tr>
<td>Ecotoxicity to Land</td>
<td>8.04</td>
</tr>
<tr>
<td>Waste Disposal</td>
<td>7.69</td>
</tr>
<tr>
<td>Fossil Fuel Depletion</td>
<td>3.28</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>3.03</td>
</tr>
<tr>
<td>Photochemical Ozone Creation</td>
<td>0.20</td>
</tr>
<tr>
<td>Acidification</td>
<td>0.05</td>
</tr>
</tbody>
</table>

1c. UK non domestic building stock data and environmental impact categories combined.

The impact of non domestic buildings in the UK (Stage 1a) was calculated for the 13 environmental impact categories (shown in Table 5) using UK non domestic building data and Life Cycle Analysis (LCA) based on the BRE Environmental Profiles 2008 methodology.

The impacts determined from this LCA were adjusted (normalised) to the equivalent impact of a European citizen (e.g. the impact of UK non domestic buildings in terms of climate change might be equivalent to 240k European citizen’s environmental impact per year). Table 6 shows how the results would be expressed for the climate change impact category.
Table 6 The impact of different aspects of the UK non domestic building industry on climate change, normalised to a European citizen’s impact/year

<table>
<thead>
<tr>
<th>Environmental Impact Category</th>
<th>Construction Materials</th>
<th>Energy</th>
<th>Transport</th>
<th>Waste</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>240k</td>
<td>7,940k</td>
<td>11,900k</td>
<td>1,950k</td>
<td>23k</td>
</tr>
</tbody>
</table>

Note: The unit for the figures in Table 6 is an “Ecopoint”. 100 Ecopoints are equivalent to one European person’s environmental impact over a year.
Stage 2: Establish relative impact of each category

2a. Sum of impacts and percentage contribution

For each environmental impact category (Table 5) the normalised impacts for the five BREEAM categories were summed together and the % contribution from the five identified BREEAM categories to the impact category was calculated. The results for the climate change impact category are illustrated in Table 7.

Table 7 The percentage contribution to climate change from the five identified BREEAM categories

<table>
<thead>
<tr>
<th>Environmental Impact Category</th>
<th>Total</th>
<th>Construction Materials</th>
<th>Energy</th>
<th>Transport</th>
<th>Waste</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>22,053k</td>
<td>1%</td>
<td>36%</td>
<td>54%</td>
<td>9%</td>
<td>0%</td>
</tr>
</tbody>
</table>

2b. Combining percentage contribution with environmental impact category weighting

The next step combines the percentages, as demonstrated Table 7, with the expert panel weightings, illustrated in Table 5, for example of the original 21.64% for climate change (see Table 5), 36% of this relates to energy and 54% to transport etc. (see Table 7). From this a new contribution table was produced. The results for the climate change impact category are illustrated in Table 8.

Table 8 The combined panel weightings with the percentage contributions to each impact category from the five identified BREEAM categories

<table>
<thead>
<tr>
<th>Environmental Impact Category</th>
<th>Table 1 Weighting</th>
<th>Construction Materials</th>
<th>Energy</th>
<th>Transport</th>
<th>Waste</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>21.64%</td>
<td>0.2%</td>
<td>7.79%</td>
<td>11.67%</td>
<td>1.92%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Finally, the total contribution for each BREEAM category was summed together to give an overall weighting for each of these categories across all the environmental impact categories.

2c. Remaining BREEAM categories

The remaining categories within BREEAM (i.e. Management, Health and Wellbeing and Land Use and Ecology, Pollution) were weighted according to an earlier consensus based study carried out by BRE. Weightings for these final four categories were then re-normalised with the weightings for the other five categories to 100% in total.
Stage 3: Factors

There are a further three factors, defined by BRE experts which contribute to the total impact of design and construction in the environment:

- an influence factor (influence of the project team on that category)
- a local conditions factor (factor to reflect local conditions) and
- a technological factor (factor to reflect any specific local technologies)

Influence factor

Once normalised, an influence factor was applied to the BREEAM categories. This factor is based on the potential (over the building’s life) that the project team has on influencing each of the impacts during the procurement of the building. The factor is applied on the following scale:

0.25 - small influence of project team
0.50 – moderate influence
0.75 - significant influence
1.00 – complete influence

The category weightings were multiplied by the above factors and renormalised to give overall European weightings.

Local conditions factor

In order to adapt these European weightings internationally, the categories are divided into global and local issues according to their impact.

Global categories – Energy, Transport, Materials, Management

Local categories - Health and Wellbeing, Water, Land Use and Ecology, Pollution

The global issues are not amended at this stage as the importance of their impact is deemed to be global and therefore not affected by local conditions.

A questionnaire is sent to local experts in the geographical area being considered asking about environmental issues of importance in their region. Using these data, local correction factors are entered into a calculator (on a basis of 0.5-2) according to the climatic conditions, e.g. water would be factored as illustrated by the list below:

- 0.5 - No natural drought conditions prevail (e.g. Norway)
- Limited natural drought conditions prevail (e.g. England)
- 1.5 - Medium natural drought conditions prevail (e.g. Mediterranean)
- 2.0 - Severe natural drought conditions prevail (e.g. Middle East)

The calculator applies multiplication factors to take account of these variations in impact and the results are renormalised to 100%.
Technological factor

The final step in this process is to establish if there are any technological differences in the country/area being considered from that typical within Europe, that need to be reflected in the weightings to properly reflect their impact. Whilst this has not frequently occurred an obvious example of this is the desalination process used to procure potable water in widespread areas of the Gulf. This process has significantly differing impacts from those used within Europe and therefore the building and environmental experts consulted felt it appropriate to reflect this within in the weightings.

6.8 Incorporation of environmental data into fire tools

Some questions, for example, ‘what are the environmental implications of different fire incident strategies?’ or ‘How are occupants of surrounding buildings impacted by fire?’ may best be answered by the application of existing environmental data and assessment methods to fire modelling and simulation tools. If these tools do not already exist, then further study will be required to understand whether such tools need to be developed, or whether a project could establish results which could be applied in general practice.

The inclusion of such environmental data into existing tools should be relatively straightforward, as LCA data per tonne of material, and impact assessment methods are available and should be able to plug into data on the mass of materials, or types of emissions.
Consideration of the assessment baseline/target

As has already been stated, the conclusions and recommendations of this project are required to provide clear information to assist Communities and Local Government in developing their priorities for future research on how (or whether) to include environmental protection and sustainability in Approved Document B and how (or whether) to include the impacts of fire in the Communities and Local Government wider sustainability agenda for buildings and construction.

In the light of the information and discussions presented above, it is apparent that the environmental impact of fire (in an occasional building), and the environmental impact of fire protection (in all buildings) can only be evaluated and compared if the objectives of the fire protection measures are defined.

In the UK (specifically England and Wales) the fire safety provisions recommended by AD B to satisfy the requirements of the Building Regulations are to provide a level of fire protection appropriate for the protection of people “in and about” buildings. But even these measures necessarily have an environmental impact. In seeking to properly identify and compare these impacts it is proposed here that any future research seeks to analyse the environmental impact of fire and fire protection (for each purpose group) against a number of related “base-lines” as follows (see also Figure 12):

7.1 Option 1

This option assumes a building that complies with AD B. and that additional fire protection measures are considered solely to minimise the environmental impact of any fire.

What is the overall sustainability impact (i.e. benefits versus disbenefits) of providing additional fire protection measures specifically for the purposes of improved sustainability impact? i.e. are there any sustainability/environmental benefits to be achieved by providing additional fire protection?

7.2 Option 2

This option assumes a building that has no fire protection (e.g. as if Part B of the Building Regulations was not applied). Consider those fire safety/fire protection measures that are introduced to ensure that the building complies with AD B.

What is the overall sustainability impact (i.e. benefits versus disbenefits) of providing fire protection measures specifically and solely for the purposes of satisfying AD B? i.e. what are the sustainability/environmental benefits that are achieved by providing only a life-safety level of fire protection?

7.3 Option 3

This option assumes a building that has no fire protection (e.g. as if Part B of the Building Regulations was not applied). Consider those measures that are introduced to ensure that the building complies with Part B (i.e. a fire engineered solution) selected to seek minimal environmental impact.
What is the overall sustainability impact (i.e. benefits versus disbenefits) of providing fire protection measures specifically for the purposes of satisfying Part B of the Building Regulations via a fire engineered solution? i.e. what are the sustainability/environmental benefits that are achieved by providing a life-safety level of fire protection via fire safety engineering? For a variety of solutions, how do these benefits/disbenefits compare with those from Option 2?

7.4 Option 4

This option assumes a building that has no fire protection (e.g. as if Part B of the Building Regulations was not applied). Consider those fire protection measures that might be introduced to ensure that the building has maximum sustainability benefit (i.e. ignoring life safety).

What is the overall sustainability impact (i.e. benefits versus disbenefits) of providing fire protection measures specifically for the purposes of maximum sustainability benefit? i.e. are there any sustainability/environmental benefits to be achieved by providing any type of fire protection?

7.5 Option 5a

This option assumes a building that has no fire protection (e.g. as if Part B of the Building Regulations was not applied). Consider those fire protection measures that might be introduced to ensure that the building both complies with Part B and has maximum sustainability benefit.

What is the overall sustainability impact (i.e. benefits versus disbenefits) of providing fire protection measures for the purposes of both satisfying Part B of the Building Regulations and maximum sustainability benefit (i.e. a fire engineered solution)? i.e. what are the sustainability/environmental benefits (if any) that are achieved by providing fire protection for life safety and sustainability?

7.6 Option 5b

As for Option 5a, but where sustainability is considered first, then life safety. (These benefits/disbenefits might be expected to be similar (but not identical) to Option 5a, above.)
Figure 12 Assessment baseline/targets
8 General discussion

As was identified at the inception of this project, the subject of fire and the environment and building’s sustainability is wide ranging and covers a large number of issues.

This scoping study has sought to identify:

a the potential impact of a building fire on the environment; a range of issues have been identified, some of which require further research

b the impact of fire protection on the environment (i.e. the environmental impact of providing fire safety components and systems in a building); a range of issues have been identified, many of which can be assessed using existing tools but some of which require further research, and

c the scope for addressing such issues through the Building Regulations or another suitable vehicle, such as the Code for Sustainable Homes. The CBA tool that has been discussed would call upon data generated by life cycle analysis, and, potentially, by the development of existing methodologies, such as BREEAM (for domestic buildings; the Code for Sustainable Homes). As discussed here, the use of the tools could be applied generically (via Building Regulations) or be building-specific (and applied via a methodology such as the Code for Sustainable Homes) (see also below). Further research is needed.

The conclusions and recommendations of this project are intended to provide clear information to assist Communities and Local Government in:

1. developing their priorities for future research on how (or whether) to include environmental protection and sustainability in Approved Document B. These issues are discussed below.

2. how (or whether) to include the impacts of fire in the Communities and Local Government wider sustainability agenda for buildings and construction. Unless the environmental impact of fire and fire protection was found to be neutral (or negative) (which is considered here to be unlikely), then any changes to The Building Regulations (or to AD B) that resulted from the outcome of further research would necessarily affect the wider sustainability agenda for buildings and construction.

This scoping study has shown that it is far from clear that any form of fire protection that is applied to the building stock through the application of the Building Regulations can have anything other than a negative environmental impact and that this is possibly an inevitability of the necessity to protect many buildings in order to mitigate the effects of the very few fires. However, the few worldwide relevant studies identified here suggest that, for a few fire protection systems this will not be the case i.e. some systems may have a net benefit to the environment.

The corollary to this is that even now Part B of the Building Regulations might be resulting in an “undesirable” environmental impact; that AD B, in particular, might need to be revised (using fire engineering principles) to assure life safety with a minimised environmental impact.
The scoping study has demonstrated that it is not possible, with our current state of knowledge, to recommend any particular course of action other than further directed research.

For CLG, the development of a transparent, effective and robust Cost Benefit (or \( \text{CO}_2/\text{Benefit} \)) Analysis tool will underpin further developments. The core elements of such a tool exist. As mentioned above, the tool might be deployed in one of three ways:

1. by permitting a generic analysis against each purpose group, leading to (purpose group-based) revisions to AD B which offer improved environmental protection (or reduced environmental impact);

2. by permitting a specific analysis for each individual building project so that the environmental impact of the fire protection in that specific building might be assessed and optimised, to minimise environmental impact. Such an analysis might be integrated with existing methodologies, such as BREEAM (or for domestic buildings; the Code for Sustainable Homes).

3. to determine the environmental impact of any proposed changes to AD B.

The key is sound data; data that at present does not exist, or exists only in a form that needs extensive processing. Of particular significance is the quantification of the building stock, for each purpose group. As is discussed in section 10, these values may be impossible to obtain and an alternative approach, based on sensitivity analysis and threshold values, may be adequately effective.
9 Conclusions

The subject of the impact of a building fire on the environment is potentially wide ranging and covers a large number of issues.

The conclusions of the scoping study are as follows:

Section 2.1: Identification of issues and collection of relevant information
- In principle, environmental impact assessment detailed design tools could be used to model the environmental impact of fire scenarios and fire protection systems.
- Input data to the model for fire and fire protection systems are needed.

Section 3: The potential impact of a building fire on the environment
- There are some data/information on all of the effluents (gas, liquid, solid products) produced in fires. However, there are large gaps and the suitability of the available data as input data to environmental impact models need to be determined.
- Energy and water usage associated with manual fire-fighting have been calculated by certain Metropolitan Fire and Rescue Services. These data need to be collected, organised and reviewed.
- Data on post-fire refurbishment (repair work that needs to be carried out on buildings damaged by fire) do not appear to exist so a means of obtaining these data needs to be determined.

Section 4: The potential impact of fire protection on the environment
- The ‘cost’ of embodied energy and other impacts for the manufacturing and use of components of fire protection systems could be determined using existing detailed environmental design tools. Relevant input data needs to be collected and reviewed.
- Each fire protection system will have different environmental impacts but these will need to be assessed using a Life Cycle Assessment for the individual system.
- For example, energy and water usage associated with water-based fire suppression systems including maintenance and the long term environmental impact of the disposal of passive fire protection systems which have been exposed to a fire need to be included in any calculations.

Section 5: Specification of a Cost Benefit Analysis tool
- The current BRE Cost Benefit Analysis (CBA) model includes the impact of a building fire on the environment in a simple way. This model needs to be extended to include the impact of a building fire on the environment and the
environmental impact of providing fire safety components and systems in a building. However, new input data and monetary conversion factors are required to do this.

- It is not clear whether the CBA analysis can be expressed entirely in monetary units or whether environmental impact should be based on carbon dioxide production and monetary units for everything else. Any tool will need to be flexible to accommodate these options that are developed. Further work is needed to determine these metrics.

- If monetary conversion factors cannot be developed, it may be possible to apply the CBA tool with the environmental aspects in different metrics, e.g. Ecopoints or carbon dioxide.

- In the short term, different monetary values could be obtained for component parts of the overall environmental impact, for example the Treasury value for carbon and Environment Agency fines for clean up.

- Initial efforts have been made to put a monetary value on an Ecopoint. However, the range of uncertainty on these estimates is very large and not sufficiently robust at this stage.

- There is insufficient data available on the UK building stock, for example the number of buildings in each purpose group, so further work is needed to extend the application of the CBA tool to a broader range of AD B purpose groups.

- Various relevant international studies have been carried out, for example in the USA, New Zealand and Sweden. Also, a cost benefit analysis was carried out for CLG on the effectiveness of residential sprinklers (excluding environmental impact). It is desirable to use these studies as a starting point for initial applications and development of the Cost Benefit Analysis tool.

**Section 6: Inclusion of fire safety in environmental/sustainability tools**

- Most environmental building level tools cover environmental rather than social issues. Further research is needed to introduce social issues relevant to fire safety into these tools.

- Impacts associated with fire and fire protection could be included within environmental building level tools if significant. However, the following need to be obtained and evaluated:
  - The significance of providing fire protection and safety systems and the differences between different approaches.
  - The benefit of providing additional fire protection beyond regulation.
  - The significance of fire events in terms of emissions from fire and replacement materials.
  - Including environmental data within existing fire tools may be an alternative, but similarly, data gathering is required.

This scoping study recommends potential areas of further work.
For completeness it should be noted that this scoping study does not include consideration of the assessment of the innovative materials used in meeting the sustainability agenda and their potential fire performance.
10 Potential areas of further work

For each of the topics described below, it will be necessary to proceed, to a greater or lesser extent, in accordance with conventional scientific methodology; namely:

- Determination (and agreement with Client/Communities and Local Government) of objectives and target outcomes.
- Initial literature review.
- Detailed literature review and abstracting.
- Statistical review.
- Acquisition of field data – pilot study.
- Acquisition of field data – detailed study.
- Small-scale experimental laboratory studies.
- Large-scale experimental laboratory studies.
- Analysis.
- Findings, conclusions and recommendations.

It has already been established that some topics will require experimental measurements. To provide an indication of the scale and nature of the current knowledge gaps (as determined by this scoping study), Appendix A has been compiled, which comprises a detailed Excel chart where the ticks show where information is currently believed to be available. It considers the three “phases” of a building’s life that have been identified here; namely "Normal" life cycle, Lifecycle with a fire, and Lifecycle with fire protection measures (see also Figure 13).

For each of these we identify the existence (or otherwise) of current knowledge against the following criteria:

- This is known.
- This can be found.
- This needs desk-based research.
- This needs experimental research.
- It is not known how to get this.

It follows that some of this research will be easy and quick, some easy but time-consuming (hence expensive). Other will be difficult but quick, or difficult and time-consuming (hence very expensive).
The programme of research offered below is intended to seek some “quick wins” (mainly based around “pilot studies”) and longer-term research, some of which may necessarily be very long term. Any models developed will need to start out simple but be capable of added complexity as the knowledge base expands.

Figure 13 shows the differing specialist information requirements for these life-cycle phases. It is evident that any robust future research will require bringing together a range of different skill and knowledge sets.

As a scoping study it is not appropriate to assign costs to these various recommendations.

In any case, any changes to AD B or related guidance will be subject to a Regulatory Impact Assessment (RIA).

![Figure 13 Building lifecycle (with fire)](image-url)
The programme of research

Project management and oversight

1. **Creation of a multi-agency “Stakeholder” Group to co-ordinate data identification and acquisition.** This would involve setting up an ongoing programme of workshops to seek to ensure that the necessary data can be obtained in the immediate to long term. As well as a variety of Government Departments and Agencies, the Group might usefully include insurance and fire and rescue service representation. (Note: such a Group would not necessarily form a “Steering Group”; ownership of any research programme should remain with the Client to avoid dilution or scope-creep).

2. **Liaison and engagement with other groups internationally working on related topics e.g. ISO, CEN.** There are current relevant ISO and CEN Fire Safety activities which have an environmental brief. Any relevant documents produced by these committees are likely to be a valuable contribution to this topic.

The environmental impact of fire

3. **A review of gases released into the atmosphere from a fire and the methods used to estimate the quantities of these.** Information needs to be gathered that links fire size and building type to the gases that will be released and the quantities of these gases. The existing literature on this subject needs to be collated and analysed fully in order to identify gaps in the current knowledge. Filling any gaps in this knowledge is anticipated to involve an experimental programme to generate the necessary data.

4. **A review of solid particulates from fires.** As item 3. above, a more detailed literature review with associated analysis should be able to identify deficiencies in the existing information. Quantities and constituents of particulates need identification for all of the building types that exist within the UK building stock. Existing data could be expanded by performing fire tests (room burns) and by obtaining samples from fires attended by the fire and rescue service. Both of these approaches are likely to be required in order to distinguish between those particulates which remain close to the incident and those that travel further afield.

5. **A review of the origin and quantity of water used by fixed fire suppression systems.** The amount of energy used in storing and discharging water for sprinklers and water mist systems is needed as input data so that this contribution to their environmental impact can be determined. These data can be obtained by a literature review. Data on the sources and amount of water used for fire suppression systems need to be collected and reviewed. If data on the amount of water stored and used in water based-suppression systems is not available, it could be calculated for different examples and types of systems.

6. **A review of the origin and quantity of water used for fire service firefighting activities.** The amount of energy used in storing and discharging water for fire-fighting activities is needed as input data so that their
environmental impact can be determined. These data can be obtained by a literature review. Existing data on the sources and amount of water used for fire-fighting activities need to be collected (mainly from Metropolitan fire and rescue services) and organised and reviewed. Gaps for other fire and rescue services across the UK will need to be filled.

7. **A review of contaminants caused by fire-fighting run off.** A literature review would be needed to identify the existing information and gaps therein. However, the work undertaken to date indicates that there is little in the way of detailed existing work in this subject. Developing a data resource in this area is likely to involve attending incidents to collect samples from fire fighting run-off in each of the property groups. It is worth noting that UK fire and rescue services are becoming increasingly aware of their own impact on the environment so may consider conducting their own work on this subject.

The environmental impact of fire protection systems

8. **Detailed identification of the materials used within fire protection systems.** This would involve identifying and quantifying the materials used for the manufacture, installation and refurbishment of fire protection systems (suppression, detection, passive).

9. **LCA analysis of the data relating to the materials used within fire protection systems.** This would involve materials used for the manufacture, installation and refurbishment of fire protection systems (suppression, detection, passive). Ultimately, the data required would be the mass of materials, manufacturing techniques used, typical life expectancy and maintenance required for each system, on a per m² or per building basis, for each building type or use. This would involve a detailed literature review, and examination of other potential data sources such as building cost models, rules of thumb, etc to obtain data. Examination of case study buildings, bottom up design models and demolition audits may also yield data.

10. **A review of the data relating to operational impacts of fire protection systems.** This would cover energy in use and materials required for typical day to day running, testing and maintenance. These will vary depending on the type and size of system and the building type.

11. **A review of the environmental damage caused by flame retardants.** This would take the form of a literature review to quantify the various environmental impacts of all types of structural flame retardants. An assessment of the interaction between these flame retardants and the extent of fire damage would also have to be made. As furniture, fixtures and fittings do not fall under the Building Regulations, the whole life impacts of these types of flame retardants will not have to be considered in this model. Rather, a study would have to be done to assess what remains of flame retardants after a fire, and the environmental impact of these remains.

Building stock survey and other statistical data

12. **An estimate of fire size, extent of damage for all fires in the UK by purpose group.** The fire size is required to give an estimate of the amount of combustion products released to the environment, and also the resources
needed to tackle the fire. This would provide distributions for the area of
damage (e.g. direct burning, smoke spread, water damage from fire-fighting),
correlated with building Purpose Group, and perhaps also
building/compartment size. This possibly could use historic UK Fire Statistics
data for area damaged (as modern fire statistics do not include this); number of
pumps attending; checking with each fire and rescue service to find if any have
these data for their area; requesting a fire and rescue service to complete an
extra form for collecting fire size data. Also, insurers’ statistics/data may be
useful.

13. **Fire load survey.** This is to provide estimates of the total mass of fuel burnt in
a fire. It has relevance not just to environmental impacts, but also in
determining appropriate fire resistance requirements for buildings. Existing
surveys may be out of date. Modern fire loads in different types of buildings,
expressed as either energy density (MJ/m²) or mass (kg/m²). The nature of the
fuel load (e.g. % cellulosic, % plastic etc) would also be recorded. This would
simply repeat the procedures of previous surveys.

14. **Environmental load survey for buildings for contents.** When a fire
damages or destroys a building, it also frequently damages or destroys the
contents. The disposal and replacement of these contents will have an
environmental impact which will need to be taken into account alongside the
environmental impact of the fire and the replacement of the building. In certain
circumstances, when a building is no longer operational, additional
environmental impact will be incurred from the extra transport required to travel
to an alternative location, which again should be considered alongside other
more direct environmental impacts of fire. It is likely that the environmental
load will vary depending on building type and use. Insurance data are likely to
be useful in generating typical inventory which can then be assessed using
high level LCA data.

15. **A property survey of all buildings in the UK.** This is needed to provide the
denominator when deriving the risk per building; not just for environmental
impact, but all fire risks such as life safety, property damage, etc. This would
determine the number of buildings by purpose group and their approximate size
and method of construction. This does not necessarily mean a door to door
survey. The information might be available from databases e.g. English house
condition survey (available), English non domestic survey (warehouses, offices
available), building control records, local councils, the land registry, Google
Earth/Street View, Experian. There might be two phases, the first to identify
and evaluate sources of data, the second to extract the data.

**Initial model development**

16. **Development of generic models for different applications for LCA and
fires.** Models need to be developed that can provide reasonably accurate
information on the relative environmental impacts of the various choices that
are available to building designers and specifiers in protecting their buildings
against fires. The average data, for all of the aforementioned parameters
divided into purpose groups and building types, needs to be identified and
collated for such models to be possible.
17. **A review of Life Cycle Assessment data.** For the materials and manufacturing processed identified in item 9, reviewing availability and quality of Life Cycle Assessment data, and hence identifying gaps and where necessary trying to obtain LCA information for specific materials or products used for fire protection. E.g. intumescents, fire retardants, sprinkler heads, components of fire detectors and alarm systems.

18. **A sensitivity analysis using data to determine the priorities of impacts.** The current BRE LCA model necessarily incorporates a range of values for each parameter for which assessment data exists (uncertainties; i.e. error bars). Once preliminary findings emerge, then a sensitivity analysis will be needed to determine the significance of the various parameters that are utilised, to establish the extent that these uncertainties may influence the outcomes of the LCA analysis, and, hence, any conclusions that are being derived.

### Development of Cost Benefit Analysis method

19. **Derivation of various cost components.** This is needed to convert environmental metrics (e.g. Ecopoints) to monetary terms, and hence enable them to be considered alongside other impacts such as life safety. A (wide) range of different conversion factors will be produced. This will involve a literature survey of as many different cost components as possible (e.g. UK Treasury value for 1 tonne of CO₂ used for carbon trading), also categorising the nature of the conversion (e.g. a direct cost, a fine imposed by Government Agencies for causing pollution, or a Willingness-to-pay figure), who pays, who benefits, etc. Each environmental impact could be converted to its Ecopoint value, and hence the cost per Ecopoint derived.

20. **Cost Benefit Analysis of sprinklers in domestic and residential premises incorporating environmental impact.** This will enable the CBA method to be developed and demonstrated using a relatively well-characterised and homogenous Purpose Group. Some work on this has also been done by others (e.g. the New Zealand residential sprinkler study), which will provide a benchmark. The method will be developed and demonstrated. The results of the CBA may have policy implications, e.g. for future revisions of AD B. A possible method is that the CBA will be spreadsheet based, coupled with Monte Carlo sampling to handle the uncertainties (which are expected to be large) in a robust manner. This would be a development from the cost benefit analysis carried out for the CLG project on the effectiveness of sprinklers in residential premises (2002) which would be extended to include environmental impact. A similar approach to the New Zealand Branz study 2008 is envisaged, where the environmental impact is expressed in Ecopoints. A range of different fire protection strategies could be examined, with a sensitivity analysis to identify the most important variables.

The detailed reviews, discussed above, require extensive data from the field, in particular with regards to the building stock in the UK for each defined purpose group. The acquisition of such data will necessarily be time-consuming and expensive, assuming that it is, indeed, technically plausible.
The use of a pilot study (or studies), where each selected purpose group is evaluated within a limited, defined and manageable locality or area would permit such studies to be carried out albeit with a more restricted scope and with less robust conclusions.

Pilot (field) studies

21. **Pilot study for warehouse input data.** A complete pilot study on a given group would highlight any further areas of work that need addressing. Warehouses are easily identifiable and expected to cover the vast majority of factors that need to be addressed for UK building stock. This study would involve selecting a study area (e.g. London); identifying and collating all the premises details (number, size, etc), visiting all relevant fires in the study area in a one year period and estimating the fire area damage, taking samples etc, categorising contents (dimensions, storage method, materials, etc).

22. **Pilot study for a selected purpose group input data.** A complete pilot study on a given group would highlight any further areas of work that need addressing. This study would involve selecting a purpose group, (e.g. offices, shops, care homes); selecting a study area (e.g. London); identifying and collating all the premises details (number, size, etc), visiting all relevant fires in the study area in a one year period and estimating the fire area damage, taking samples etc, categorising contents (dimensions, storage method, materials, etc).

23. **A study of post-fire refurbishment requirements by purpose group/occupancy and fire size.** Information on the environmental impact of refurbishment already exists within current LCA tools. However, there do not appear to be any data on the process of clearing up after a fire or the impact of fire size and consequential damage on the amount and nature of refurbishment that is required. Insurance companies keep records of the amount of money required to reinstate a property following a fire, but no detailed information on the fire itself is known to be kept. A study in this area would need to establish a relationship between fire size and environmental cost of refurbishment, in order to make use of the information. It may be worth investigating any link between insurance cost and the environmental impact of refurbishment in order to make use of existing insurance industry data.

The data collected in the pilot studies above would provide essential input to desk based studies, which might otherwise depend upon assumptions and deductions based on secondary sources, and which would be of very limited reliability.

Desk based studies

24. **Cost benefit analysis of sprinklers in warehouses incorporating environmental impact for a specific geographical area.** Warehouses are likely to be a Purpose Group where the environmental impacts of fire (and potential benefits of protection systems) are significant. These could include environmental impact related to size (compartmentation), fire load (hazard category), and various fire protection strategies. The results may have policy implications, e.g. for future revisions of AD B. This project would use the methodology and tools developed in a previous study, item 20 above, but with input data appropriate to warehouses obtained from the pilot study, item 21 above.
25. **Cost benefit analysis of sprinklers in a selected purpose group incorporating environmental impact for a specific geographical area.** The results would be similar to the warehouse study above, e.g. impact related to building size, type of occupants, fire protection measures, etc. This study would involve selecting a purpose group, (e.g. offices, shops, care homes). This project would use the methodology and tools developed in a previous study, item 20 above, but with input data appropriate to the selected purpose group obtained from the pilot study, item 22 above.

26. **Quantifying the impact of different fire-fighting and fire protection strategies.** Once all the relevant input data have been determined and the environmental impact models with fire have been developed, the models can be applied to quantify and compare the environmental impact of different fire-fighting protection strategies in different building types.

### Desk based studies

27. **Cost benefit analysis of sprinklers in warehouses incorporating environmental impact for a specific geographical area.** Warehouses are likely to be a Purpose Group where the environmental impacts of fire (and potential benefits of protection systems) are significant. These could include environmental impact related to size (compartmentation), fire load (hazard category), and various fire protection strategies. The results may have policy implications, e.g. for future revisions of AD B. This project would use the methodology and tools developed in the previous project, but with input data appropriate to warehouses obtained from the pilot study, item 21 above.

28. **Cost benefit analysis of sprinklers in a selected purpose group incorporating environmental impact for a specific geographical area.** The results would be similar to the warehouse study above, e.g. impact related to building size, type of occupants, fire protection measures, etc. This study would involve selecting a purpose group, (e.g. offices, shops, care homes). This project would use the methodology and tools developed in the previous project, but with input data appropriate to the selected purpose group obtained from the pilot study, item 22 above.

29. **Quantifying the impact of different fire-fighting and fire protection strategies.** Once all the relevant input data have been determined and the environmental impact models with fire have been developed, the models can be applied to quantify and compare the environmental impact of different fire-fighting protection strategies in different building types.

### Research into practice

The findings of the above studies would need to be carefully analysed and recommendations for changes to Approved Document B and/or guidance documents developed.
11 Acknowledgements
The authors would like to acknowledge the positive contributions of the following colleagues to the structured ideas workshop: Kelvin Annable, Peter Fardell, Tom Lennon and Kristian Steele.

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Appendix A – Chart showing an indication of the scale and nature of the current knowledge gaps

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<th>Phase</th>
<th>Component</th>
<th>Parameter</th>
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Notes:

- Need to investigate the relative importance of the 13 factors of LCA
  - Waste disposal
  - Nuclear waste
  - Stratosphere ozone depletion
  - Fossil fuel depletion
  - Climate change
  - Eutrophication
- Mineral resource depletion
- Water extraction
- Ecotoxicity to fresh water
- Ecotoxicity to land
- Toxicity – human
- Acidification
- Photochemical ozone creation

- Other gases need to include CO, SO₂, H₂S, HCN, etc.
- Liquid wastes need to include dissolved gases, sulphur compounds, other water-soluble wastes, oils, tars, etc.
- Solid wastes need to include dioxins, heavy metals, soot.
- Need to gather data to be able plot probability distribution for degrees of damage for a fire occurring in each purpose group and how this distribution is affected by each fire protection method.
- Effluents from post fire demolition are assumed to be different from "normal" demolition due to fire damage. This could be investigated with a survey following FRSs to incidents.
- Post fire raw materials includes fire-fighting water, foam (or other extinguishing agents - halons, CFCs), fire retardants, etc.