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DCLG Final Research Report:

BD 2537

Sprinkler installation trends and fire statistics for warehouse buildings

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Fire Safety

BD 2537

Sprinkler installation trends and fire statistics for warehouse buildings

Final Research Report

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Executive Summary

DCLG have proposed to include a provision for limiting the maximum compartment size of unsprinklered warehouse buildings to 440,000 m^3 in the revised version of Approved Document Part B (Fire safety) of the Building Regulations. The aim of this project is to provide further evidence for DCLG, which can be used to underpin the final decision concerning the eventual maximum compartment size of unsprinklered warehouse buildings.

The conclusions and recommendations of this project are as follows.

- Planning application data suggest that, over a three year period, four warehouse buildings might be constructed which would be affected by the proposed volume limit of 440,000 m^3, assuming a height of 11 m gives an area of 40,000 m^2.
- Interviews and questionnaires suggest that 20% to 50% of warehouse buildings would voluntarily have sprinklers installed.
- The cost benefit analysis, based on UK Home Office Fire Statistics, aerial photographs to determine the distribution of warehouse sizes and sprinkler cost data, enabled a maximum compartment area (not volume) of unsprinklered warehouses to be determined.
- Uncertainties in the data and the assumptions made in the analysis lead to an uncertainty in the value of compartment area for which sprinklers would be cost-effective. This led to the derivation of a probability distribution for the compartment area, the parameters of which were:
  - The 90% confidence level for sprinklers to be cost-effective is given by a warehouse at least 85,000 m^2 in area
  - The 80% confidence level is given by a warehouse at least 35,000 m^2 in area
  - The 50% confidence level is given by a warehouse at least 9,650 m^2 in area.
  - The 95% confidence level could not be determined due to a large uncertainty, other than it occurred for a warehouse greater than 100,000 m^2 in area.
- A sensitivity analysis has been carried out using significantly higher values for the cost of damage/m^2 and this suggests that the areas above would be significantly reduced for sprinklers to become cost effective. However, in order to reduce the uncertainty in the maximum unsprinklered warehouse area that should be permitted, a more accurate figure for the average cost of damage per m^2 must be established.
- It is recommended, with the intended revision to the method of collection of fire statistics, that the area damaged data should be routinely collected again for all fires. It would also be beneficial if the actual building area was included in the statistics, rather than having to be inferred from the percentage damage.
- Uncertainties in the costs had less effect on the overall results, than uncertainties in the expected benefits.
- The life safety benefits of sprinklers are expected to be negligible, relative to the costs.

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1 Background

DCLG have proposed to include a provision for limiting the maximum compartment size of unsprinklered warehouse buildings to 440,000 m^3 in the revised version of Approved Document Part B (Fire safety) of the Building Regulations [1]. This proposal is in response to concerns about the trend for the construction of very large storage buildings and the associated increased fire risk.

A partial Regulatory Impact Assessment [2] has been produced in support of these proposals. This takes into account that many of these buildings are voluntarily provided with sprinkler protection for the purpose of property protection and business continuity.

This project provides further evidence which may be used by DCLG to underpin the final decision concerning the eventual maximum compartment size of unsprinklered warehouse buildings.

2 Project objectives

The aim of the project is to produce a short research report for DCLG and the Part B Working Party, which will eventually be published on the Approved Document B page of the BRE website. The specific objectives of the project are to seek to:

- Quantify the number of warehouse buildings (i.e. those in excess of 440,000 m^3) that would be affected by the proposed changes
- Make estimates of the proportion of the warehouse buildings affected which are likely to have sprinkler protection installed voluntarily
- Review available fire statistics to identify any trends relating to warehouse buildings
- Analyse the number of fires reported to determine whether they would fall into either the storage or industrial purpose groups defined in Approved Document B
- From the above work, determine the potential final upper compartment limit, especially in light of comments that DCLG received from stakeholders responding to the consultation suggesting a lowering of the limit.

To achieve these objectives, there are two main tasks, which are:

Task 1: Initial review of existing data and produce interim report

Task 2: Review meeting with DCLG, provision of further data and production of final report.

3 Analysis from previous draft Regulatory Impact Assessment

A draft partial Regulatory Impact Assessment (RIA) [2] was produced as part of the public consultation package in support of proposed changes to Approved Document B [1]. For each of the proposed amendments, the RIA identified the associated risk, usually the risk of death or injury to building occupants from fire, addressed by the change as well as the likely benefit in terms of the reduction of that risk. The associated economic and environmental costs and benefits were also identified.

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In respect of the proposal for a requirement for a maximum unsprinklered warehouse compartment size of 440,000 m^3, the factors considered in the RIA were:

- the typical size (floor areas and heights) of modern warehouses and the number of them constructed each year
- the fire risks associated with such warehouses
- the degree to which sprinklers could reduce these risks
- the economic cost of not only installing sprinklers but also the impacts of the proposed maximum compartment size on warehouse operations, and
- the degree to which sprinklers are already installed in warehouses (primarily for insurance purposes).

The driver for this proposal was that there was felt to be a trend for new warehouses to be constructed much larger than existing warehouses and that this might lead to an increase in the risks to people using these buildings. This concern was heightened because of the possibility of increased occupation of storage warehouses (e.g. because of the rise of internet shopping), whereas traditionally, warehouses generally have had low levels of occupation.

An associated economic driver was that there are some 20 Local Acts (including the London Building Acts) which have numerous fire safety provisions including those relating to large storage buildings. An eventual aim of the proposed amendment therefore was to repeal the Local Acts and, in the case of warehouses, introduce a single national compartment size for England and Wales so as to prevent any economic distortions between adjacent areas, i.e. to ensure a warehouse is not constructed in one area in preference to another because of differences in the provisions for maximum compartment size. Any changes had to be justified on a risk assessment basis, i.e. removing any local provisions should not increase the risks to persons in and about buildings.

In order to investigate the issues raised above and to compile information to use in the draft partial RIA to support the proposed amendment, a number of avenues were researched. Information used in the draft partial RIA for Approved Document B comprised:

- **Home Office fire statistics.** Statistics [3] relating to fires in warehouse buildings were analysed. This was undertaken as part of the wider effort on assessing the impacts of Local Acts which showed that the additional requirements of the Acts have no significant impact on life safety, but they do improve property protection in warehouses (and car parks) [4].
- **Planning applications.** Planning applications [5] were analysed to establish the number, location and floor area of warehouses and other industrial purpose buildings that are constructed each year. In the end, only some of this information was used directly in the RIA because of data obtained from the warehouse industry (see bullet point below).
- **Information from the UK Warehouse Association and a large logistics company .** The UK Warehouse Association and a large logistics company (X), were interviewed by telephone about the proposed amendment, and the interview with X was supplemented by a completed questionnaire. The information from these two parties focussed on the size of modern warehouses, the impacts of compartments on warehouse construction cost and operations, how often sprinklers are provided and whether Local Acts have caused any local distortions.

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On the basis of this information, it was concluded in the draft partial RIA that, overall, the proposal would impose no significant costs on the warehouse industry since it already largely complied with the requirement. Indeed, there may be some cost savings because there would be a single national compartment size which would eliminate any possible local distortions. This potential economic benefit was not quantified in the RIA due to the lack of available information. On the basis of analysis of available fire statistics and the above information, it was suggested that the proposal in terms of life safety would be risk neutral, i.e. would neither improve the situation nor make it worse. As an aside, changes to Building Regulations cannot be justified on the basis of reducing the risk to property and contents as the current locus of the Regulations is the health and safety of persons in and around buildings. The current locus of Building Regulations also encompasses the energy efficiency of buildings (e.g. Part L [6]) and the welfare and convenience of building users (e.g. Part M [7]). The argument here is that these issues are addressed through insurance.

4 Programme of work and findings

4.1 Number of warehouse buildings (i.e. those in excess of 440,000 m^3) affected by the proposed changes

Planning applications were analysed to establish the number, location and floor area of warehouses that are constructed each year.

Planning data from 2000, together with partial data from 2001 and 2002 [5], has been analysed to identify potentially affected buildings. This data source has recently been subject to some building re-categorisation and data processing.

Planning application data for 2005 had not arrived at the time of writing.

4.2 Estimated proportion of warehouse buildings affected likely to have sprinkler protection installed voluntarily

Information has been obtained from the UK Warehouse Association and three logistics companies. These were interviewed by telephone and by questionnaire about the proposed amendment. The information from these parties focussed on the size of modern warehouses, the impacts of compartments on warehouse construction cost and operations, how often sprinklers are provided and whether Local Acts have caused any local distortions. Summaries of the telephone interviews and the completed questionnaires are given in Appendix A. Some of the key findings were:

- Over the last 15 years, new build warehouse footprint size has grown because the retail sector has moved towards fewer but larger Regional Distribution Centres or even a single National Distribution Centre. The result is that typically 25,000 to 40,000 m^2 buildings can be required to fulfil these requirements (and even larger buildings, e.g. 80,000 m^2 are not uncommon) but anything from say 10,000 m^2 are still required. To quote a typical size is difficult as the final size is dependent on customers' requirements and building layout.
- A typical new build warehouse roof height is 11.5 m to 12 m, so a product clear height would generally be about 10.5 m. Such a height would mean that the proposed maximum unsprinklered compartment size of 440,000 m^3 would correspond to a floor area of about 42,000 m^2. Therefore, the proposed limit would capture a limited number of unusually large warehouses.

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- Typically, the Local Acts have a provision of 7,000 m^3 maximum storage volume so the proposed limit would be substantially higher.
- Analysis of planning application data suggest that about a quarter of warehouses and related industrial buildings are built in areas covered by Local Acts, but experience suggests that the Acts have not caused local distortions since warehouse location are dictated by a customer's supply needs rather than other considerations.
- Larger warehouses do not necessarily mean more people, as this depends on their operation. If it is 'full pallet' then automation means that material is quickly loaded with fork lift trucks involving minimal number of persons. If it is 'picking', i.e. taking goods out of pallets/boxes, then the numbers of people will increase.
- Larger warehouses are not necessarily perceived by the warehouse industry to represent a greater fire risk. The main factors that are considered to improve fire risks are good management and security, hazard specific selection of active and passive fire protection systems and limiting travel distances.
- Some modern warehouses are already provided with sprinklers, estimates vary from 20% to 50%. There appears to be no relationship between warehouse size and whether sprinklers are installed. The key driver for sprinkler protection is tenant/customer/insurance requirements, this is influenced by economic return in terms of rental and handling charges (hence sprinklers tend to be installed only on long term contracts). However, sprinklers have been installed where required by Local Acts. In some cases, given the move towards larger Regional Distribution Centres and even National Distribution Centres, it makes business sense to retailers to use sprinklers to protect large quantities of stock from loss due to fire.

4.3 Determination of potential maximum compartment size of unsprinklered warehouse buildings

4.3.1 Outline of method for estimating costs and benefits of installing sprinklers in warehouse buildings of different sizes

The objective of this part of the project was to determine a building size, for which the installation of sprinklers would be cost effective. The costs of the system have been subdivided into fixed and area-dependent installation costs, plus an annual maintenance cost. The benefits that have been considered are the estimated reduction in deaths and injuries, plus estimated reductions in the amount of property damage.

UK Home Office fire statistics [3] for the years 1994-1998 have been used for this study. After 1998, details of area damaged per fire is not always recorded. (Prior to 1999, about 98% of all fire records have this information). The statistics data were filtered, to look at fires originating in warehouse buildings. Industrial and retail buildings were not included.

A study [8] has suggested that a significant number of fires, that have been assigned a "warehouse" origin in the fire statistics, might actually have been in retail buildings. The confusion in the classification seems to arise in the case of "retail warehouses", which resemble warehouses in terms of building contents, but are more akin to shops in terms of the number of people present during trading hours.

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It has been decided to base this analysis on all the “warehouse” buildings fires recorded in the statistics. The cost-benefit analysis (Appendix B) shows that property protection is far more important than life safety in determining whether sprinklers will be cost effective. Hence the distinction between “warehouses” and “retail warehouses” should not affect our results.

In order to perform this analysis, it is necessary to know the numbers of warehouses in different size categories, and the number of fires and degree of damage in warehouses of different sizes. However, obtaining this information was not straightforward, as explained in the following sections.

Before progressing, a comment should be made concerning uncertainties. These are generally quoted in the form “ $x \pm y$ “, where x is the value, and y the corresponding uncertainty. In most cases there has been an implicit assumption/approximation that the value is Normally-distributed. The uncertainty will be quoted either as 1 or 2 standard deviations of the distribution (the text will specify which). Usually this Normal approximation gets worse as the uncertainty gets larger. This explains why the uncertainty (particularly when quoted as 2 standard deviations) may appear to be larger than the value, when a negative value would be a physical impossibility. Although the standard deviation is correct, the distribution is skewed, rather than symmetrical as would be the case for a Normal distribution. Nevertheless the “± “ symbol has been retained as a convenient shorthand.

4.3.2 Determination of number of warehouse buildings in different size ranges

It is unfortunate that the distribution of numbers of warehouses of different sizes does not seem to be directly available. Nevertheless, there were two ways in which this distribution could be estimated:

a) using aerial maps from the “Google Earth” search engine [9]

b) using data from planning applications.

4.3.2.1 Warehouse size distribution from aerial maps

The original intention was to use aerial maps to estimate the size of warehouses, since this information was not recorded directly in the fire statistics database. There are about two-thirds (471 out of 669) of the warehouse fire records, where the postcode of the warehouse is also given. By entering the postcode into the “Google Earth” search engine, an aerial map of the area could be displayed, from which the building footprint could be directly measured.

The Google Earth approach, whilst not very effective at determining the actual footprint of the building where the fire occurred (usually because there was more than one candidate in or near the postcode given in the fire statistics), does give an estimate of the general size distribution of warehouses.

A typical search result, showing a number of warehouses in the target area, and the measurement of the “best” candidate for the warehouse having the fire (the one nearest the postcode marker) is shown in Figure 1.

Not all of the postcodes corresponding to the addresses of warehouse fires in the period 1994-1998 gave useful results. In a few cases, the postcodes in the fire statistics database no longer exist. In other cases, there were no warehouses in the field of view. A common problem, affecting about half (180) of the postcodes searched for, was that the aerial maps were not of sufficient quality for warehouses to be identified, much less measured.

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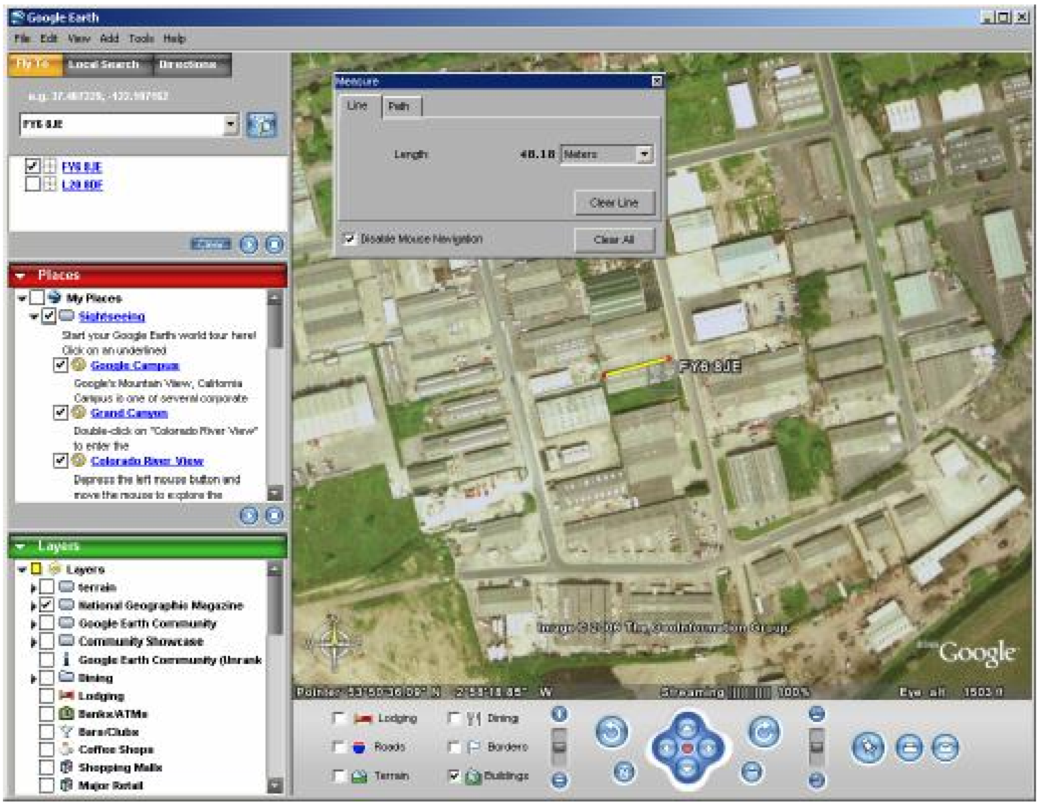
There were 214 postcodes giving useful results. 1205 warehouse sizes were measured. Although it was rarely clear which warehouse, if any, corresponded to the warehouse recorded in the fire statistics, it was, nevertheless, felt that the size distribution derived from the measured sample was a reasonable reflection of the population of all warehouses in the country.

It should be noted that this approach only gives the proportions of buildings in different size categories, not the absolute number. In the absence of direct data, the fire statistics could be used to estimate the total number of buildings. BS PD 7974-7 [10] quotes data from the mid 1970's that the number of fires per warehouse building per year is 0.013. The fire statistics for 1994-1998 contain 1395 records of warehouse fires, leading to an estimate of 787 ± 21 fires per year.

If it is assumed that the number of fires per warehouse per year has not changed over the last 30 years, then the total number of warehouse buildings would be 60540 ± 1600.



The length of the warehouse at the location of the postcode marker is 48 m, according to the little window of the Google measuring tool. By zooming in until the "eye altitude" is about 1500 feet, the field of view is about 500 m square (according to the measuring tool). Any warehouses outside this field of view were considered to be too far away to match the postcode in the fire statistics. Where more than one warehouse exists in the field of view, as here, up to seven candidates (the nearest to the postcode marker) were measured.

Figure 1 Typical result of postcode search in "Google Earth"

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However, this assumption of unchanged probability of fire is unlikely to be correct. BS 7974 PD7 also quotes data from the mid 1970's that the number of fires, divided by the total floor area of all warehouses, is 3.3×10^{-5} fires.yr^{-1}.m^{-2}. The probability of fire depends on building size. It is 6.7×10^{-4} A $^{0.5}$ fires.yr^{-1}, where A is the building area. Using any two of the three pieces of information from BS PD 7974-7, leads to an inferred average warehouse size of about 400 m^2 in the mid 1970's. The average building size of the Google Earth sample was 1700 m^2. As the probability of having a fire rises with increasing building size, the estimate of 60,540 buildings in total is probably too high.

As the average area of the Google Earth sample is 4 times higher than the estimate from the mid 1970's, if we assume the probability of having a fire is proportional to the square root of area, then a better estimate of the average number of fires per building would be 0.026 yr^{--1}, rather than 0.013 yr^{-1}, and thus the total number of buildings would be about 30,000. If we assume the true average number of fires per building is somewhere between 1.5 and 2.5 times higher than the value in the mid 1970's (i.e. a fractional uncertainty of 0.5/2.0 = 25%), then the number of buildings would be 30,000 ± 7,500.

4.3.2.2 Warehouse size distribution from planning applications

Data from planning applications give the footprint of new buildings, so the numbers in different categories can be determined. Not all buildings for which planning applications are submitted, are actually constructed.

Data for the years 2000-2002 listed 137 applications. The average area was 7100 m^2, further evidence for a trend towards increasing warehouse size. Planning statistics up to 2005 has been applied for, but unfortunately these data have not arrived at the time of writing.

4.3.2.3 Summary of warehouse size distributions

Figure 2 shows the proportions of current, as measured from the Google Earth sample, and new build warehouse building stock, from the planning data, in different size categories. The shape of the distribution is approximately log-Normal. This graph clearly shows the trend, for new buildings to be larger than existing stock.

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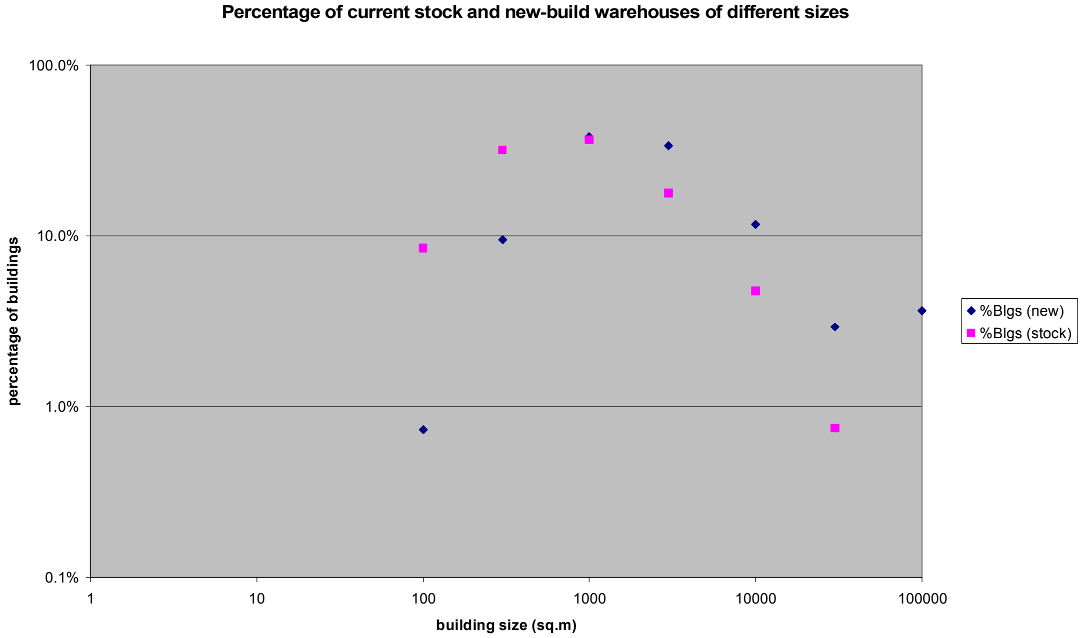

Figure 2 The percentage of current and new build warehouse building stock of different sizes

The absolute number of warehouse buildings in the different categories, based on a total of 30,000 ± 7,500 warehouses of all sizes, is given in Table 1. The uncertainty is dominated by the assumed uncertainty in the total number of buildings, except for size categories above 10,000 m^2 where the small number of buildings in the sample also increases the uncertainty in the total number of buildings in the entire population.

Size category (m^2)	Size range (m^2)	Proportion of current stock	Estimated number of warehouses*
100	56 ~ 178	8.5%	2539 ± 810
300	178 ~ 560	31.8%	9535 ± 2575
1000	560 ~ 1780	36.5%	10954 ± 2931
3000	1780 ~ 5600	17.8%	5328 ± 1518
10000	5600 ~ 17800	4.7%	1419 ± 517
30000	17800 ~ 56000	0.7%	224 ± 160
100000	56000 ~ 178000	< 0.1%	25 ± 50
*Uncertainties in the estimated number of warehouses are ± 2 standard deviations			

Table 1 Estimate of the total number of warehouse buildings in different size categories

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4.3.3 Determination of number of fires per building per year versus warehouse building area

As mentioned in the previous section, the intention was to use the “Google Earth” website to obtain aerial maps of locations where warehouse fires had occurred. The building size could then be measured directly from the aerial map. However, this approach had a number of difficulties:

- Not all the fire records contained postcode information
- Not all of the aerial maps were of sufficient quality to identify or measure building sizes
- Not all postcodes listed in the fire statistics still existed
- A number of postcodes had no obvious warehouses within the vicinity
- Most warehouses occurred in groups, rather than in isolation, thus it was not possible to identify the one corresponding to the fire origin with any certainty.

There were 215 fire records where the only problem was the ambiguity caused by a group of warehouses. The approach taken to deal with this ambiguity was to measure the sizes of up to seven buildings nearest to the postcode marker. The size of the warehouse having the fire was assumed to lie somewhere in the range defined by the maximum and minimum of these measurements.

Due to the difficulties listed above, it was decided in the end not to use the size estimates from the Google Earth measurements, for the purposes of categorising each of the fires recorded in the statistics. Nevertheless, the sample of measured warehouses was useful in deriving the distribution of sizes for the overall population of UK warehouses, as described in the previous section.

The UK Home Office fire statistics do not contain explicit details of the building size. If they did, there would have been no need to attempt to measure sizes using Google Earth. An attempt was made to obtain insurers’ data, in the hope that insurers’ records included actual building sizes. Alternatively, if insurers’ data had precise addresses, there might have been more success in using Google Earth’s maps to derive building size. This would be time consuming. However, up to the time of writing, insurers’ data have not been received. The insurers’ data have a number of features which cause difficulty:

- There is no centrally-collated database, unlike the Home Office fire statistics
- In the data published by the Fire Protection Association [e.g. 11], the date quoted is that of the insurance claim, not the date of the fire, so cross-checking with the Home Office database is not possible
- In the data published by the Fire Protection Association, the address quoted is that of the insurance office processing the claim, not the address where the fire occurred, therefore preventing cross-checking
- The insurer’s agents might have the detailed information required, but this would require the insurer to use the insurance policy numbers (which identify the incident in their main databases) to cross-check with their agents’ records.

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Fortunately, there was a way to progress. The Home Office fire statistics contained more implicit information on building size than was initially realised. These statistics record the area damaged by fire, and also an estimate of the fraction of the room (or floor) damaged. Together, these data allow an estimate of room (or floor) size. Additionally, the statistics record similar information for total damage (all causes), which enables another estimate of area to be made for the same building, as a cross-check.

If, for example, the percentage of the compartment damaged is f%, and the area of damage is A_d, then the estimated size of the compartment is ($100.A_d$ / f%) m^2.

In order to estimate the building size, only the subset of fires originating in the warehouse storage area itself was used. Fires in other areas, e.g. attached offices, would be unlikely to give any useful information concerning the size of the storage space. Conversely, it was assumed that any fires originating in storage areas could give a size estimate from either the percentage of room damage, or the percentage or floor damage – the warehouse “room” occupying most of the building floor area.

Where multiple estimates of the building size could be made for the same fire, the maximum and minimum of these estimates defined a range, within which the true area was deemed to lie. If the range spanned several size categories, as defined in Table 1, then the fire was “shared” among each category, as appropriate.

At this point, it is important to note that, since 1994, the Home Office fire statistics do not contain a record of every fire visited by the fire services. Instead, each fire record is given a weighting (1.0 or higher) which is the reciprocal of the fraction of fires visited that are actually included in the database. This fraction varies from brigade to brigade. This weighting factor needs to be accounted for when estimating the total number of fires. However, the proportion of fires in each building size category should probably be derived from the fire records, without weighting.

For example, suppose there is a record of a fire in a building whose size is estimated to be 10,000 m^2, which has a weighting of 5 (i.e. one in five fires visited by the brigade are recorded in the electronic database). It is highly unlikely that the other 4 fires that were not recorded in the database also had building sizes of 10,000 m^2. Therefore, the unweighted records should be used to avoid introducing a bias into the derived distribution.

The distribution of the number of fires occurring in different building sizes is given in Figure 3 and Table 2.

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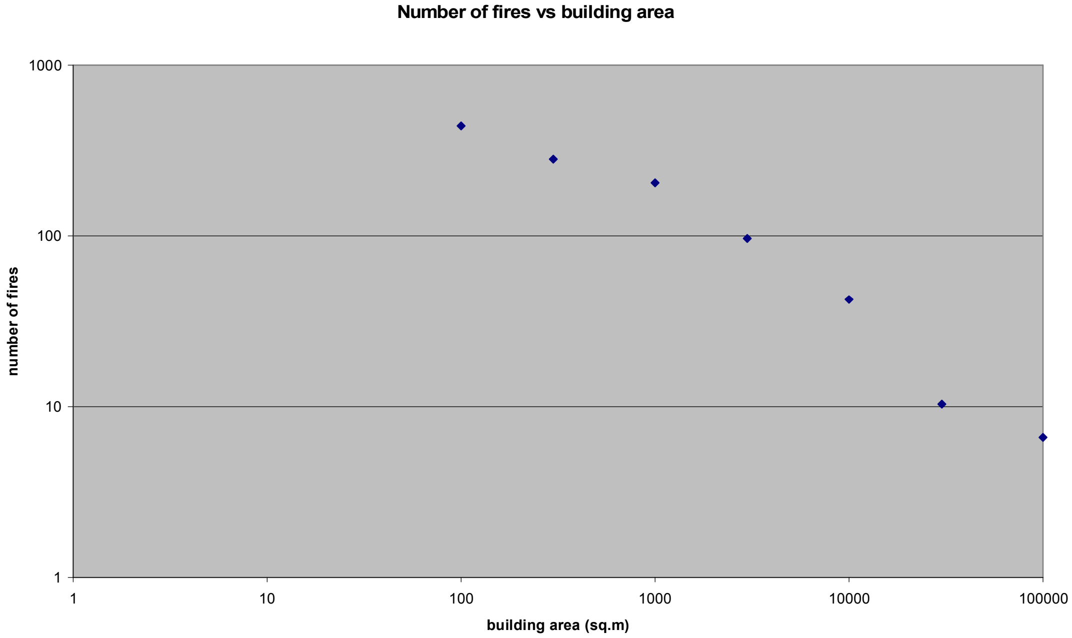

Figure 3 Estimated number of fires occurring in different building sizes, over a five year period 1994-1998

Size category (m^2)	Size range (m^2)	Number of fires* in 1994-98	Estimated number of fires per 1000 buildings per yr**
100	56 ~ 178	438	59 ± 20
300	178 ~ 560	282	10 ± 3
1000	560 ~ 1780	205	6 ± 2
3000	1780 ~ 5600	96	6 ± 2
10000	5600 ~ 17800	42	10 ± 5
30000	17800 ~ 56000	10	16 ± 15
100000	56000 ~ 178000	7	90 ± 192

*The fires listed in this column are the subset where area and percentage damage was recorded, allowing an estimate of building size. There were 1080 fires over the 5 year period in this subset, compared to 1834 fires in total. The estimate of the number of fires per 1000 buildings has assumed that the fires, for which no size information could be inferred, follow the same distribution as the other fires.

**Uncertainties in the estimated number of fires per 1000 buildings per year are ± 2 standard deviations.

Table 2 Distribution of fires in buildings of different sizes and estimated number of fires per building per year

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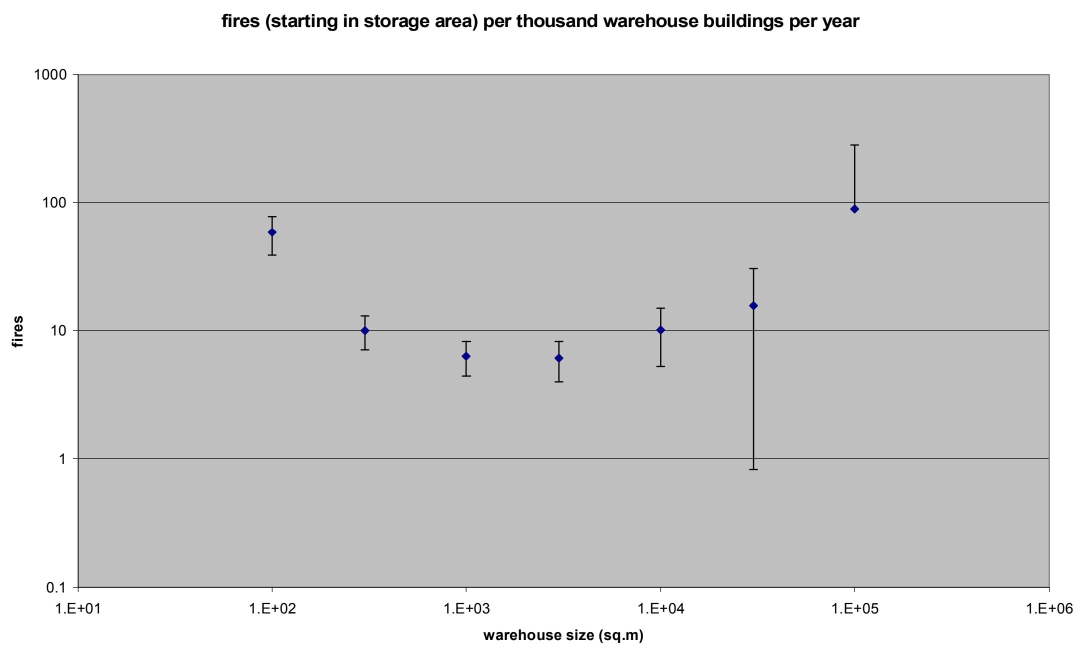

Note: for a building size of 105 m^2, the lower error bar goes to zero (which cannot be plotted on logarithmic axes)

Figure 4 The number of fires starting in the storage area in warehouse buildings per year, as a function of building size

The fire statistics for 1994-1998 contain 675 records of warehouse fires originating in storage areas, leading to an estimate of 367 ± 14 fires per year. For all warehouse fires 1994-1998 (storage and other areas), there are 1395 records, leading to an estimate of 787 ± 21 fires per year. As explained earlier in this section, it was not possible to make a reliable estimate of building size when the fire did not start in the warehouse storage area. If it is assumed that the numbers of fires starting in other areas are independent of the building size (because, for example, the number of offices would not depend on warehouse size), then the number of other fires per 1000 buildings per year is 14.0 ± 3.5.

4.3.4 Average area damaged per fire versus warehouse building area

Determination of the average area damaged followed a similar procedure to the determination of the number of fires in warehouses of different sizes. The estimate of room (or floor) size was made as described earlier, using either the area damaged by fire and the estimate of the fraction of the room (or floor) damaged, and/or the information for total damage (all causes) and percentage damage.

If, for example, the percentage of the compartment damaged is f%, and the area of damage is A_d, then the estimated size of the compartment is $(100.A_d / f\%)\ m^2$.

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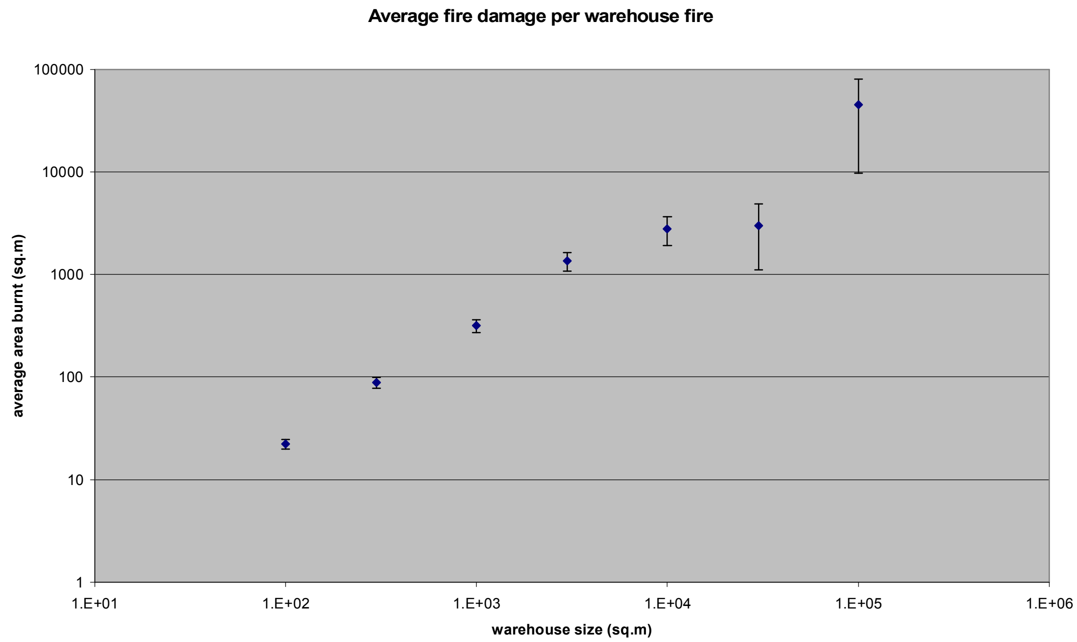
In order to estimate the building size, only the subset of fires originating in the warehouse storage area itself was used. It was assumed that the warehouse "room" occupied most of the building floor area.

Where multiple estimates of the building size could be made for the same fire, the maximum and minimum of these estimates defined a range, within which the true area was deemed to lie. If the range spanned several size categories, as defined in Table 1, then the fire was "shared" among each category as appropriate. The damage was not shared equally over several size categories, but instead allocated pro-rata in order to maintain the same percentage damage over each of the categories the fire was being assigned to.

For example, one fire had a burnt area of 50~99 m^2, which was described as 50% of the room of origin. The total area damaged was specified as 250 m^2, and described as 100% of the floor of origin. The burnt area leads to a warehouse size estimate of 150 m^2, which lies in the range of the 100 m^2 category, whereas the total damage gives a warehouse size estimate of 250 m^2, lying in the 300 m^2 category. The averaging approach would have assigned half of the fire to the 100 m^2 category, and half of the fire to the 300 m^2 category. One-quarter of the damage would be allocated to the 100 m^2 category, and three-quarters to the 300 m^2 category, since the ratio of the building areas in the two categories is 1:3.

In order to estimate the average damage, over all records, the number of fires per category and the damage caused by each fire are summed. The average damage for the area burnt by the fire was evaluated, and also the area damaged by all causes (e.g. smoke damage). The results are illustrated in Figures 5 and 6 and Table 3.



Error bars are 1 standard deviation

Figure 5 Average area of fire damage per fire, as a function of warehouse size

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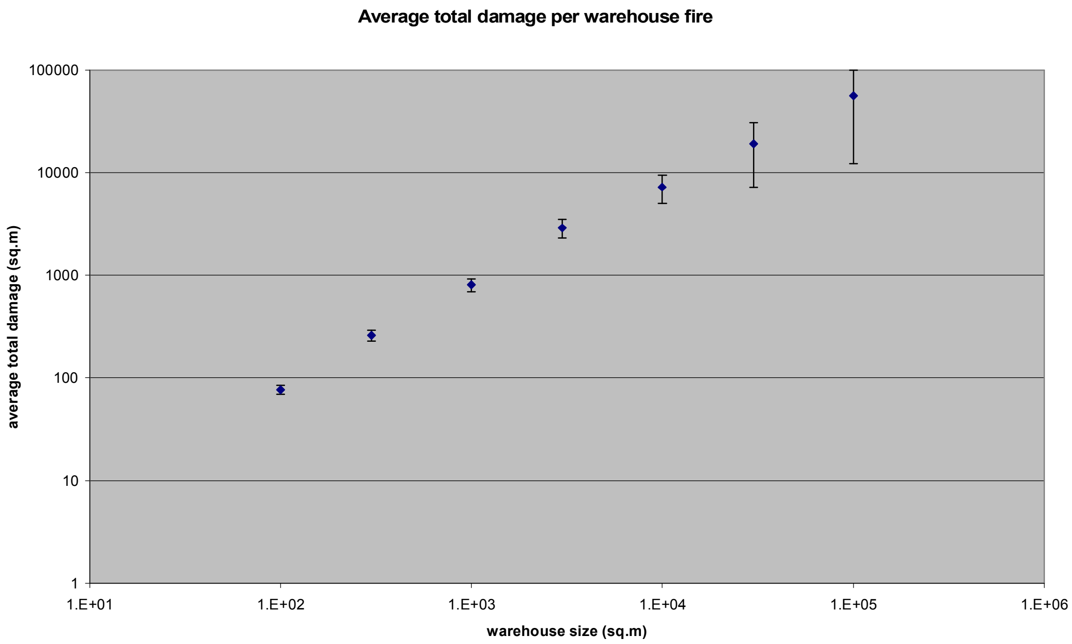

Error bars are 1 standard deviation

Figure 6 Average area damaged (all causes) per fire, as a function of warehouse size

Size Category (m^2)	Size range (m2)	Area of fire damage (m^2)	Area of total damage (m^2)
100	56 ~ 178	22 ± 5	77 ± 15
300	178 ~ 560	88 ± 21	261 ± 63
1000	560 ~ 1780	318 ± 90	807 ± 227
3000	1780 ~ 5600	1361 ± 558	2883 ± 1179
10000	5600 ~ 17800	2779 ± 1723	7229 ± 4460
30000	17800 ~ 56000	2977 ± 3741	19003 ± 23710
100000	56000 ~ 178000	44981 ± 70509	55987 ± 87645
*Uncertainties in the area damaged per fire are ± 2 standard deviations			

Table 3 Average area damaged per fire in warehouse buildings of different sizes

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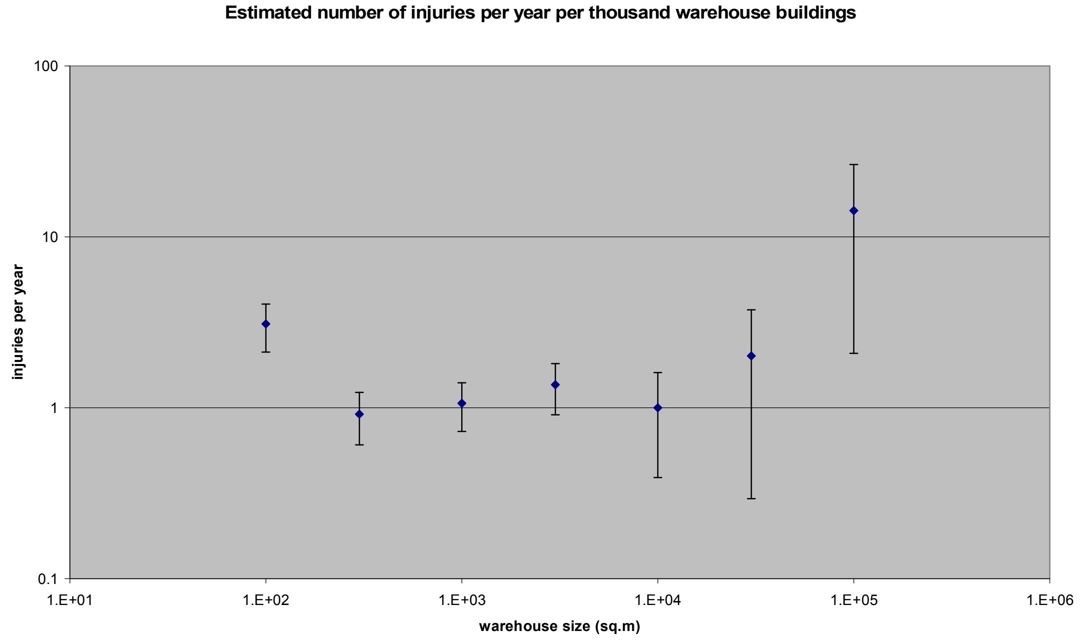
4.3.5 Determination of the number of casualties, versus warehouse building area

In the same way the average area damaged per fire, as a function of building size, can be calculated, the number of casualties can also be calculated. The subset of fires originating in the storage areas, for which a building size estimate could be made has been used, to deduce the shape of the distribution. Casualties from fires in the storage areas, where a building size estimate could not be made, were assumed to have the same distribution shape. Casualties from fires originating elsewhere were assumed to be distributed according to the numbers of buildings in each size category (i.e. the probability of a casualty for a fire outside the storage areas did not depend on building area).

In the five year period 1994-1998, there were 444 records where the building size could be estimated. In these recorded fires, there were 102 casualties. There were a further 231 records of fires starting in the store areas (where building size could not be estimated), that caused an additional 15 casualties. In other areas, there were 720 records, and 71 casualties.

All of the casualties were injuries. There were no deaths.

The estimated number of injuries, per year, per 1000 warehouse buildings, for different warehouse sizes is given in Figure 7 and Table 4.



Error bars are 1 standard deviation.

Figure 7 Estimated number of injuries per year per 1000 warehouse buildings versus warehouse size

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Size category (m^2)	Size range (m^2)	Injuries per year per 1000 buildings*
100	56 ~ 178	3.1 ± 1.9
300	178 ~ 560	0.9 ± 0.6
1000	560 ~ 1780	1.1 ± 0.7
3000	1780 ~ 5600	1.4 ± 0.9
10000	5600 ~ 17800	1.0 ± 1.2
30000	17800 ~ 56000	2.0 ± 3.4
100000	56000 ~ 178000	14.2 ± 24.3
*Uncertainties are ± 2 standard deviations		

Table 4 Estimated number of injuries per year, per 1000 warehouse buildings for different sizes

As the number of injuries is very low (36.7 ± 2.7 per year, over all warehouse fires), the total cost of this is about £2.3m per year (see section 4.3.7). Given the estimate of 30,000 warehouse buildings in total, then, on average, each can afford to spend £80 per year on sprinklers, assuming, optimistically, that sprinklers would be 100% effective in reducing injuries. Clearly, utilising this data, it could be difficult to justify the provision of sprinklers solely on safety grounds.

This is also apparent in the cost benefit calculations, presented later in Appendix B.

4.3.6 Calculate expected reduction in area damaged and casualties per year

If it is assumed that sprinklers operate with a reliability r, once the fire size has reached a sufficient size, then the greatest possible reduction in area burnt would arise if an operating sprinkler always prevented the fire from getting any larger. Previous research [12] has suggested that the threshold fire size might be in the region of 3 m^2. For each of the warehouse fires in the database, if the area burnt (in the absence of sprinklers) was A_b, then the average area burnt by that fire in a sprinklered warehouse would be given by

$$A_b' = A_b$$ if $A_b < 3\ m^2$, and

$$A_b' = 3 + (1-r).(A_b - 3)$$ if $A_b > 3\ m^2$

If we make the further assumption that A_t, the total area damaged (due to all causes, most likely smoke), would also be reduced by the same amount as the burnt area, then

$$A_t' = A_t$$ if $A_b < 3\ m^2$, and

$$A_t' = \left((1-r) + \frac{3.r}{A_b}\right).A_t$$ if $A_b > 3\ m^2$

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The reduced areas of damage can be averaged, for each building size category, in the same way that the original areas of damage were calculated, see section 4.3.4.

With the reliability of the sprinklers, r, assigned a value of 94% [13], the reduced damage, as a fraction of the original average damage without sprinklers, is shown in Figure 8.

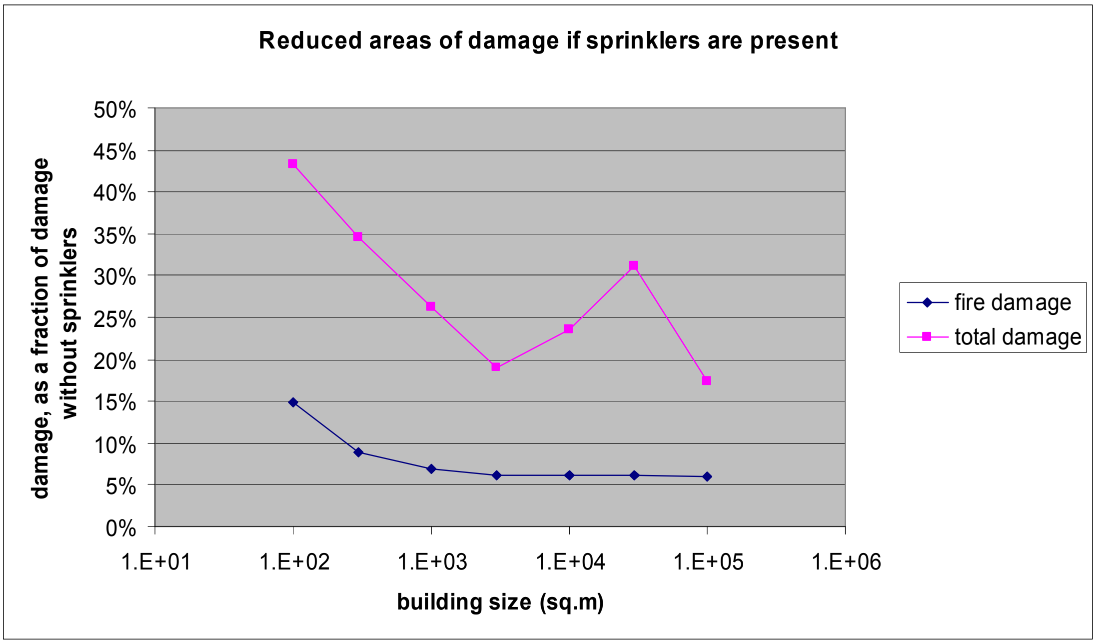

Figure 8 Estimated reduction in area damaged per fire

The assumptions leading to the result above are likely to be optimistic. Even if sprinklers operate, they will not always prevent the fire from growing larger. The effect on the total damage is even more uncertain. Other research [14] suggests a reduction in the area damaged by 73% ~ 82%. It was not clear if this reduction applied to the area burnt, or the total damage.

The results in Figure 8 only apply to fires originating in the warehouse storage areas. It is not clear whether sprinklers would also be fitted to other areas. If not, the sprinklers could only operate once the fire had broken through into the storage area. As the fire would be much larger to do this, than the size required to trigger sprinkler operation, the likelihood of sprinklers being able to control the fire would be reduced. It was also observed that the distribution of area damaged had a lower mean value for other fires, compared to fires starting in the storage areas. This may be due to increased compartmentation in the other areas, preventing many fires from spreading beyond the room of origin.

Due to the uncertainties involved, a simpler approach to estimating the effect of sprinklers has been adopted, assuming that the average damage caused by fires originating in the warehouse storage areas is reduced by a factor of 85% ± 10%, which takes account of both the reliability and effectiveness of the sprinkler system. This reduction was assumed to apply to both the area burnt, and the total area damaged.

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The reduction in damage for other fires was assumed to be a fraction of the reduction for warehouse fires. This fraction has been assumed to be 30% ± 10%.

For example, if the average area damaged, by fires starting in the store area, for a particular warehouse size category is 1000 m^2, then sprinklers would reduce this damage by 85% (850 m^2). The reduction for other fires would be 30% of the reduction for warehouse fires, i.e. 0.3 x 850 m^2 = 255 m^2.

It was not possible to draw any reliable conclusions from the fire statistics about the effectiveness of sprinklers in reducing the number of injuries. As the number of injuries was not expected to make a substantial difference to the cost benefit analysis, it was decided to assume a reduction of 50% ± 50%.

There were no deaths in any warehouse fire during the period 1994-1998. Whatever value is taken for the effectiveness of sprinklers in reducing deaths, this will have no effect on the cost benefit analysis.

4.3.7 Convert these reductions into monetary terms (benefits)

It was hoped that data from insurers would be available, that would enable us to assign an average value per m^2 of area damaged. However, at the time of writing, such data have not been made available. The impossibility of correlating the fire statistics with data published by the FPA has already been discussed in section 4.3.7.

Alternatively, BS 7974 PD 7 gave the average cost of fire in various occupancies in 1966, which could be inflated to current prices.

Table A.12 — Average loss per fire at 1966 prices (£'000)

Occupancy	Sprinklered single storey	Sprinklered multi storey	Non-sprinklered single storey	Non-sprinklered multi storey
Textiles	2.9	3.5	6.6	25.2
Timber and furniture	1.2	3.2	2.4	6.5
Paper, printing and publishing	5.2	5.0	7.1	16.2
Chemical and allied	3.6	4.3	4.3	8.2
Wholesale distributive trades	—	4.7	3.8	9.4
Retail distributive trades	—	1.4	0.4	2.4

Figure 9 Table A12 from BS 7974 PD 7 which gives figures for the average financial loss per fire

Figure 9 suggests that, at 1966 prices, the cost of fire for a warehouse building would be in the region of £4,000 ± £3,000. These losses would presumably arise from total damage, not just the area burnt. For all 1392 recorded warehouse fires in 1994-1998 which included data on total damage, the average total damage was 715 ± 40 m^2. Therefore, the average cost of damage would be £5.60 ± £4.20 per m^2 (1966 prices).

A graph of Retail Price Index, see Figure 10, has been used to calculate the rise in the cost of damage. The RPI in 1966 was assigned a value of 15.1, and the value in 2006 was 193.4. Prices have therefore risen by a factor of 12.8 since 1966. The average cost of damage would therefore be £71.70 ± £53.80 per m^2 (2006 prices).

This cost is for the total damage, not just the area burnt.

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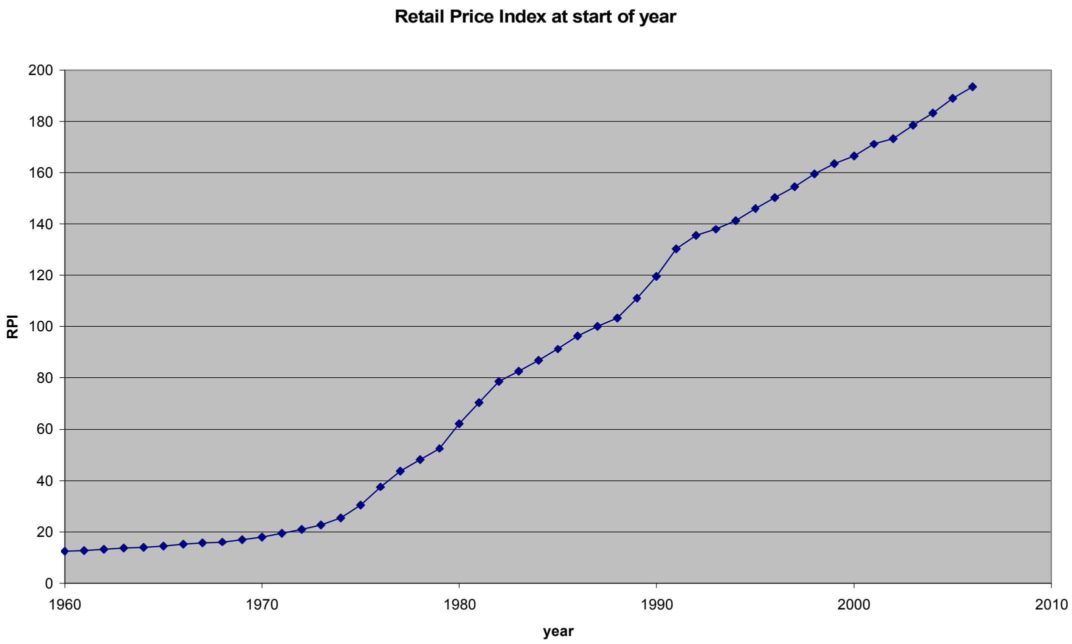

Figure 10 Retail Price Index at the start of each year

The value that has been calculated for the average damage per fire has implicitly assumed that the average area of damage per fire has remained the same since 1966. However, it is known that the average size of warehouses is increasing over time, see section 4.3.2.3, and that the average total damage per fire increases with increasing warehouse size (A_t proportional to ${A_b}^{0.8}$), from the slope of the graph in Figure 6). In section 4.3.2.1 it was estimated that the average warehouse size has quadrupled since the early/mid 1970's, therefore the average fire size would roughly triple. If the average fire size (without sprinklers) in 1966 was one third of its current value, the cost of fire per m^2 would be three times higher.

Hence, the estimated fire loss per m^2 in 2006 prices has been taken as £210 ± £150.

The values (Willingness-to-Pay) of preventing death and injury, at 2002 prices, were evaluated as £1.243m and £58.3k, respectively [15]. Inflating these over a four year period to 2006 prices, and assuming an average annual growth in GDP of 2.4% [16], gives values of £1.367m and £64.1k, respectively. Note: GDP is used to inflate life safety figures, whereas RPI is used for property values [17].

4.3.8 Determine cost of installing sprinklers versus warehouse building area

Information about installation costs, water supplies costs and lifetime maintenance costs for warehouse buildings of various sizes has been received [18]. Although estimates for warehouse buildings of areas 1000, 3000, 10000, 30000, and 100000 m^2 were asked for, the results received were expressed in terms of “small”, “medium” and “large”.

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This terminology has been interpreted, as follows:

“small” < 1000 m^2

“medium” 1000 m^2 ~ 3000 m^2

“large” > 10000 m^2 and above

The results are presented in Tables 5 and 6.

Sprinkler system	Small warehouse	Medium warehouse	Large warehouse
No racks	£26	£24	£22.50
Single level in-rack	£30	£28	£27
Two levels in-rack	£37	£34.50	£33.50
Three levels in-rack	£45	£42	£41
ESFR at roof level	£35	£33	£32
Value used in CBA	£34.60 ± £9.50	£32.30 ± £9.00	£31.20 ± £9.25

Table 5 Costs (per m^2) of sprinkler installation

Sprinkler system	Small warehouse	Medium warehouse	Large warehouse
No racks	£30k	£35k	£42k
Single level in-rack	£35k	£38k	£40k
Two levels in-rack	£40k	£42k	£45k
Three levels in-rack	£42k	£45k	£50k
ESFR at roof level	£40k	£42k	£45k
Value used in CBA	£37.4k ± £6k	£40.4k ± £5k	£44.4k ± £4k

Table 6 Costs of water supplies

The water supply costs should also include a value of £40 per metre for below ground piping. This factor has not been included in the cost benefit analysis, due to uncertainty in the amount of piping required.

Generic figures supplied [19] show values for annual maintenance between £750 ~ £1,500 per year.

Both the sprinkler installation per m^2 and water supply costs are one-off, and need to be discounted over an appropriate time period. Some researchers have used a time period of 20 years [20], but it is preferred to follow Ramachandran [21] in using a value of 40 years for the payback period. An uncertainty of ±10 years has been assumed for this value. In accordance with Treasury Guidelines [22], a discount rate of 3.5% per annum was applied.

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The capital recovery factor (the fraction of the initial cost that is paid off each year) is given by

$$K = r\frac{(1+r)^y}{(1+r)^y - 1}$$

where r is the rate of interest expressed as a decimal fraction, e.g. 0.035 for 3.5%, and y is the length of the payback period in years. If the uncertainty in the payback period is Dy, then the uncertainty in the capital recovery factor is

$$\Delta K = \left(\frac{\partial K}{\partial y}\right).\Delta y$$

Using the relation

$$\frac{d(a^x)}{dx} = \ln(a).a^x$$

and the quotient rule for differentiation

$$\left(\frac{u}{v}\right)' = \frac{u'.v - v'.u}{v^2}$$

then with some further manipulation it can be shown that

$$\Delta K = K.\ln(1+r).\left(1 - \frac{(1+r)^y}{(1+r)^y - 1}\right).\Delta y$$

4.3.9 Cost benefit calculations

Using estimates for the costs and benefits derived in previous sections, cost benefit calculations have been performed for sprinkler installation in different sizes of warehouse building. The installation and water supply costs have been discounted to give an equivalent annual cost, which is then added to the annual maintenance. The benefits include prevention of death and injury, and property protection based on total damage. Details of the calculations are presented in Appendix B. The results are summarised here, in Table 7 and Figure 11.

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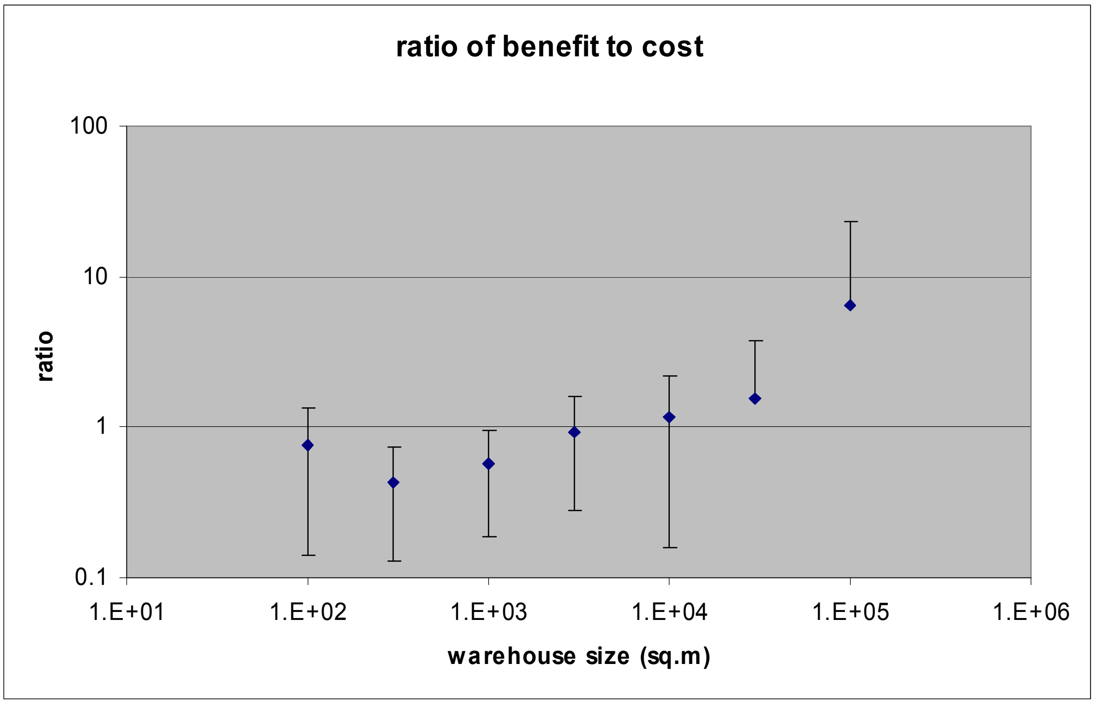
Warehouse size (m^2)	Annual cost (£k)	Annual benefit (£k)	Ratio of benefit (£B) to cost (£C)	Confidence level that £B > £C
100	1.3 ± 0.5	1.0 ± 0.7	0.75 ± 0.61	21%
300	1.6 ± 0.6	0.7 ± 0.4	0.43 ± 0.30	0%
1,000	2.6 ± 0.7	1.5 ± 0.9	0.57 ± 0.38	1%
3,000	5.7 ± 1.5	5.3 ± 3.4	0.93 ± 0.65	42%
10,000	15.7 ± 4.8	18.4 ± 15.0	1.17 ± 1.01	63%
30,000	45.0 ± 14.0	68.6 ± 95.8	1.53 ± 2.18	68%
100,000	147.2 ± 46.6	941.9 ± 2468.6	6.40 ± 16.89	74%
Uncertainties are 2 standard deviations				

Table 7 Results of cost benefit analysis for sprinklers in different warehouse sizes



For warehouse sizes above 10,000 m^2, the error bars (2 standard deviations) extend to a ratio of zero – which cannot be plotted on a logarithmic scale.

Figure 11 Ratio of benefits to costs

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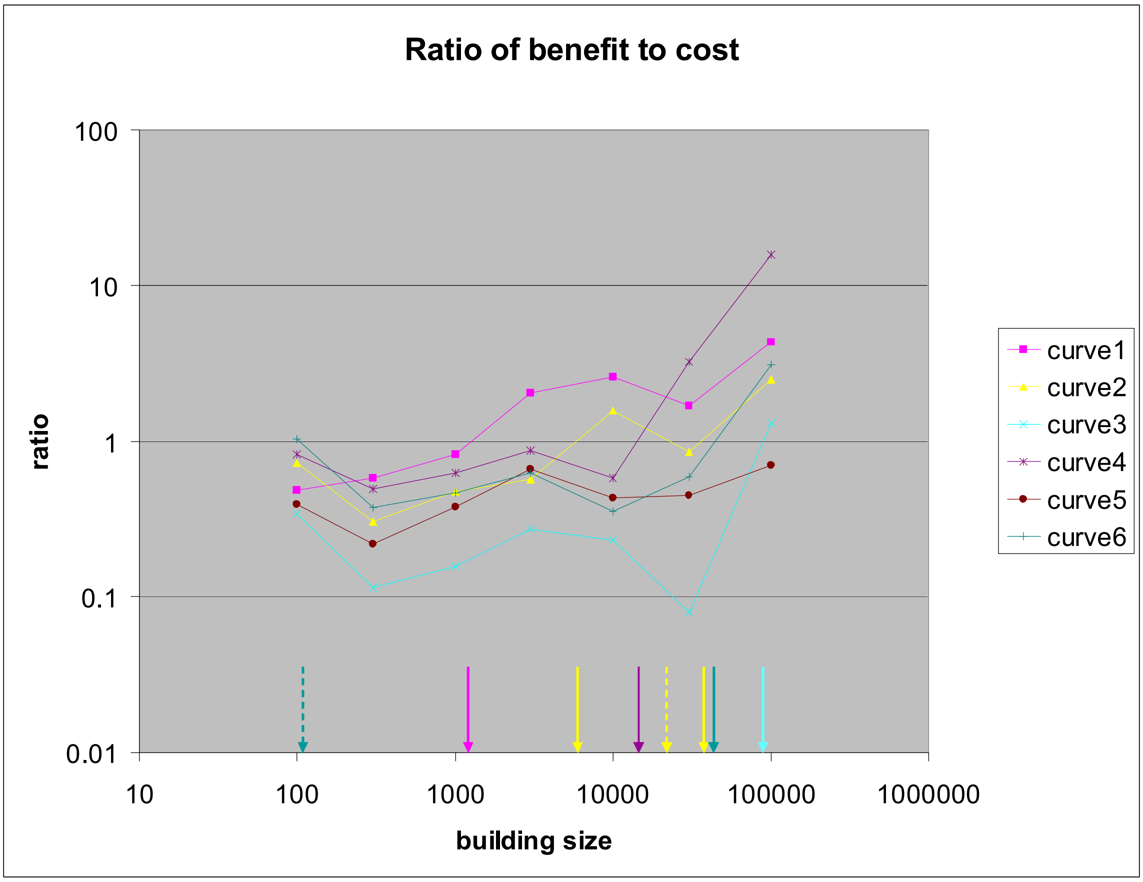
4.3.10 Estimate of warehouse size for which sprinklers will be cost-effective

Sprinklers will be cost-effective when the ratio of expected annual benefit to expected annual cost is greater than 1. If a curve is plotted through the data points of the graph in Figure 11 above, this curve will cross the threshold (ratio > 1) at a value lying somewhere in the region of 10,000 m^2. However, as the cost-benefit ratio is subject to uncertainty, different curves could be plotted as the values of the cost-benefit ratios vary within their error bars. Each different curve will give a different value of warehouse size, for which the cost-benefit ratio is 1. This argument is illustrated by Figure 12.



The arrows show where each of the curves has the ratio equal to 1. Note that some curves (curve2 and curve6) have more than one building size for which the ratio equals 1, and others (curve5) have no values of building size below 100,000 m^2 for which a ratio of 1 is achieved.

Figure 12 Illustration of how variability in the cost benefit ratios for different building sizes leads to uncertainty in the value of building size for which sprinklers will be cost-effective

The process illustrated by Figure 12 was repeated for one thousand possible curves. If a curve did not achieve a ratio of 1 for a size below 100,000 m^2, the size was taken as 100,000 m^2. If a curve had several

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values of size that gave a ratio of 1, then values where ratio was decreasing with size were ignored, and other values combined to give an “average” value of size where the ratio equalled 1.

For example, curve2 in Figure 12 has three warehouse sizes where the ratio is 1; these are 5850 m^2, 22600 m^2 and 35500 m^2. Ignoring the middle value (because this lies on a segment of the curve where the ratio is decreasing with increasing size), the “average size” for curve2 is derived from the anti-log of the average of the logarithms of the other two sizes, and take the value 14470 m^2.

$$A = 10^{\left(\frac{\log(5850)+\log(35500)}{2}\right)} = 10^{4.16} = 14470$$

The cumulative Density Function for the warehouse area at which sprinklers become cost-effective (ratio>1) is given by Figure 13.

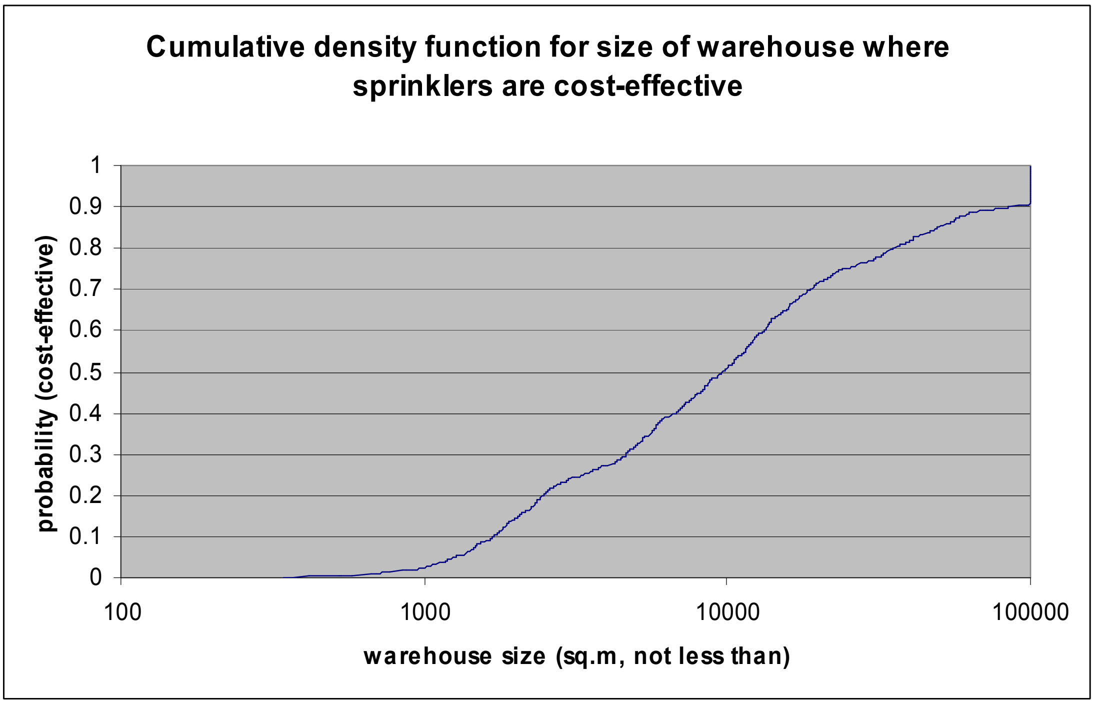

Figure 13 Cumulative density function for the warehouse size where sprinklers are cost-effective

Unfortunately, it is not possible to set a 95% confidence limit for the warehouse size at which sprinklers will be cost-effective. This is because 9% of all the curves considered did not give a ratio>1 for a size less than 10^5 m^2. However, some other fractiles of the distribution can be defined from the data:

- The 90% confidence level is given by a warehouse at least 85,000 m^2 in size
- The 80% confidence level is given by a warehouse at least 35,000 m^2 in size
- The 50% confidence level (and median of the distribution) is given by a warehouse at least 9,650 m^2 in size.

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4.3.11 Sensitivity analysis

It has been suggested that the height of warehouse buildings (assumed to be up to ~11 m) may have been less for buildings constructed before the 1960's. The assumption that the cost of damage per m^2 should be inflated in accordance with the rise in RPI (section 4.3.7) may therefore give an underestimate, as the costs should also rise in accordance with the increase in height. The extent of this height increase is unknown. Some additional cost-benefit calculations have been performed, following the procedure of sections 4.3.9, 4.3.10 and Appendix B, but using different values for the cost of damage. Full details for the results of these calculations have not been included. The end results are presented below.

If the cost of the damage quadrupled (i.e. a value of £840 ± £600 per m^2, rather than £210 ± £150 per m^2, then 70% of the possible curves had benefit-to-cost ratios greater than 1 for all warehouse sizes. The large uncertainties in the benefits for large warehouses (30,000 m^2 or more) made it impossible to extract sensible values for higher fractiles of the distribution of warehouse size that ensures sprinkler cost-effectiveness.

If the cost of damage doubled (i.e. a value of £420 ± £300 per m^2, rather than £210 ± £150 per m^2), then the fractiles of the cumulative density function are:

- The 95% confidence level is given by a warehouse at least 19,000 m^2 in area
- The 90% confidence level is given by a warehouse at least 11,000 m^2 in area
- The 80% confidence level is given by a warehouse at least 6,000 m^2 in area
- The 50% confidence level is given by a warehouse at least 1,000 m^2 in area.

4.3.12 Conclusions of cost benefit analysis

Costs and benefits have been estimated for sprinklers fitted in warehouses of different sizes, with the aim of identifying a size of warehouse that would enable sprinklers to be a cost-effective investment. The end-point of the analysis was a distribution of the probability that sprinklers would be cost-effective, as a function of warehouse size.

There were many sources of uncertainty, which leads to a relatively large uncertainty in the final answer. Therefore, it was not possible to determine the 95% fractile of the distribution, other than the fact that it occurred for a warehouse size in excess of 100,000 m^2. However, other fractiles could be derived:

- The 90% confidence level is given by a warehouse at least 85,000 m^2 in area
- The 80% confidence level is given by a warehouse at least 35,000 m^2 in area
- The 50% confidence level (and median of the distribution) is given by a warehouse at least 9,650 m^2 in area.

It was necessary to make a large number of assumptions during the analysis, which increased the uncertainty level in the results. Some of the uncertainty could be reduced if better data were available, for example if the actual distribution of warehouse sizes was known, rather than being inferred. A major source of uncertainty arose from the cost of damage per m^2. If it is possible to correlate insurance statistics with the Home Office fire statistics, then a more accurate calculation would be permitted. However insurance data arrived too late for us to attempt this (and there was no guarantee of success, even if we had tried).

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Other sources of uncertainty arise due to the small sample size, for fires in large warehouse buildings (both the fires and the buildings being few in number). This uncertainty could be reduced if statistics were available for more than the five year period 1994-1998 that we analysed. However, after 1998 the area damaged was less likely to be recorded in that statistics. It is recommended, with the intended revision to the method of collection of fire statistics, that these data should be routinely collected again for all fires. It would also be beneficial if the actual building area was included in the statistics, rather than having to be inferred from the percentage damage.

A sensitivity analysis has been carried out using significantly higher values for the cost of damage/m^2 and this suggests that the areas above would be significantly reduced for sprinklers to become cost effective. However, in order to reduce the uncertainty in the maximum unsprinklered warehouse area that should be permitted, a more accurate figure for the average cost of damage per m^2 must be established.

Uncertainties in the costs had less effect on the overall results, than uncertainties in the expected benefits.

The life safety benefits of sprinklers are expected to be negligible, relative to the costs.

4.4 Stakeholders' comments

Stakeholders' comments from the Approved Document B consultation have been obtained, reviewed and relevant information extracted, as follows.

a) It was felt by some respondents that a single, consistent national limit to compartment size of warehouse buildings and the repeal of the Local Acts is reasonable.

b) It was felt by some respondents that this should be expressed as a maximum area and height rather than a volume to be consistent with Table 12 in Approved Document B (2000 Edition).

c) However, it was felt by some respondents that the proposed volume of 440, 000 m^3 is too large, especially where: dangerous goods are stored, very large travel distances are involved, large numbers of occupants, there is a danger of structural collapse of building structure and physiological issues on fire-fighters entering the building. This could be a warehouse of dimensions 200 m by 200 m by 11 m high.

d) Other figures for maximum compartment sizes were proposed by some respondents but these were not substantiated by supporting evidence.

- For comparison, other countries limits were cited, 5,000 m^2 for normal hazard and 2,000 m^2 for higher hazard in Denmark, 3,000 m^2 in France, 1,200 m^2 for normal hazard and 400 m^2 for higher hazard in Germany, 1,000 m^2 in the Netherlands, 1,800 m^2 for normal hazard and 1,200 m^2 for higher hazard in Norway, 2,000 m^2 for normal hazard and 1,000 m^2 for higher hazard in Spain. In the USA, the maximum travel distance in new build or existing unsprinklered storage premises is 61 m for normal hazard and 23 m for high hazard and 122 m and 30 m, respectively, if sprinklered.
- Most Local Acts require provisions for warehouse volumes above 7,000 m^3.
- Maximum volumes of 10,000 m^3 and 50,000 m^3 and an area of 8,000 m^2 were suggested.

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4.5 Conclusions and recommendations of this project

The conclusions and recommendations of this project are as follows.

- Planning application data suggest that, over a three year period, four warehouse buildings might be constructed which would be affected by the proposed volume limit of 440,000 m^3, assuming a height of 11 m gives an area of 40,000 m^2
- Interviews and questionnaires suggest that 20 to 50% of warehouse buildings would voluntarily have sprinklers installed.
- The cost benefit analysis, based on UK Home Office Fire Statistics, aerial photographs to determine the distribution of warehouse sizes and sprinkler cost data, enabled a maximum compartment area (not volume) of unsprinklered warehouses to be determined.
- Uncertainties in the data and the assumptions made in the analysis lead to an uncertainty in the value of compartment area for which sprinklers would be cost-effective. This led to the derivation of a probability distribution for the compartment area, the parameters of which were:
  - The 90% confidence level for sprinklers to be cost-effective is given by a warehouse at least 85,000 m^2 in area
  - The 80% confidence level is given by a warehouse at least 35,000 m^2 in area
  - The 50% confidence level is given by a warehouse at least 9,650 m^2 in area.
  - The 95% confidence level could not be determined due to a large uncertainty, other than it occurred for a warehouse greater than 100,000 m^2 in area.
- It was necessary to make a large number of assumptions during the analysis, which increased the uncertainty level in the results. Some of the uncertainty could be reduced, e.g. if better data were available, if the actual distribution of warehouse sizes was known, the cost of damage per m^2, if it were possible to correlate insurance statistics with the Home Office fire statistics, if the sample size for fires in large warehouses was larger.
- A sensitivity analysis has been carried out using significantly higher values for the cost of damage/m^2 and this suggests that the areas above would be significantly reduced for sprinklers to become cost effective. However, in order to reduce the uncertainty in the maximum unsprinklered warehouse area that should be permitted, a more accurate figure for the average cost of damage per m^2 must be established.
- It is recommended, with the intended revision to the method of collection of fire statistics, that the area damaged data should be routinely collected again for all fires. It would also be beneficial if the actual building area was included in the statistics, rather than having to be inferred from the percentage damage.
- Uncertainties in the costs had less effect on the overall results, than uncertainties in the expected benefits.
- Based on available fire statistics, the life safety benefits of sprinklers are expected to be negligible, relative to the costs.

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- Figures for maximum warehouse compartment sizes were proposed by some respondents as part of the Approved Document B review consultation but these were not substantiated by supporting evidence.

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Appendix A – Summary of telephone interviews with UK Warehouse Association and logistics companies and questionnaires

A.1 UK Warehouse Association

- Has seen growth in large warehouses, as well as increases in height usually because of higher land prices.
- Height of 5 pallets is quite common and is the maximum that can be reached by a turret truck. It is equivalent to 35 ft (6 ft per pallet plus 1 ft space between pallets), or just under 11 m. Has seen heights of 8 pallets or 60 ft (18 m), and some maybe as high as 100 ft (30 m). At these heights, cranes are required (an example of manufacturer is Clico in Kettering) as is racking to store goods.
- Not a supporter of compartmentation. He would prefer to see the use of sprinklers and smoke vents. Has experienced differences in views of local authorities and, more importantly, fire brigades in the required levels of fire protection. Has used smoke screens to stop the spread of smoke. He does not like compartmentation because:
    - increased capital cost of building, e.g. 10-15% increase if warehouse split into two compartments. Suggested speak to Simons of York as builders or other warehouse companies such as X, Tiverton Britain and Hayes as they probably have in-house builders who could give cost estimates
    - handling difficulties, e.g. use of conveyor-belts, movement of fork-lifts trucks and HGVs
    - alternative is use of fusible links, e.g. open door that is closed when fire detected.

A.2 X

Re-iterated UK Warehouse Association points but also said:

- Increase footprint of building so rental will rise
- Reduction in visibility because of compartmentation and if CCTV required then more cameras needed
- Valving of sprinklers and connection/number of alarms
- Management and flow of materials generally will be compromised
- Larger warehouses but do not necessarily mean more people. Depends on operation. If it is ‘full pallet’ then automation means that material is quickly loaded with fork lift trucks involving minimal number of persons. If it is ‘picking’ (i.e. taking stuff out of pallets/boxes) then number of people will increase
- Have high standards of fire management because all of a client’s stock may be tied up in one location so loss in a fire would be a significant lose to both X and client.

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A.3 Y

Re-iterated UK Warehouse Association previous points but also said:

- Typical floor area are 10,000 to 80,000 m^2
- They have installed sprinkler because of Local Acts, not because of business reasons
- Generally, sprinklers cannot be justified on economic grounds
- Smaller compartments could penalise the business by 5-10%
- No relationship between warehouse size and sprinklers
- Approximately 50% of warehouses are sprinkler protected.

A.4 Z

Re-iterated UK Warehouse Association previous points but also said:

- Typical floor area are 25,000 m^2
- They have found sprinkler to add a significant cost. Additionally, they have found when their tenant/customer and hazard changes, they have to change the sprinkler installation.
- Fire risk is better dealt with by addressing escape routes, fire loads, management and security (in particular fires caused by electrics and arson), rather than by restricting compartment size.
- Smaller compartments would have a significant economic and commercial impact
- Sprinkler protection is generally selected if required by a tenant/customer, no dependency on warehouse size.
- Approximately 20% of warehouses are sprinkler protected.

A.5 Second representative of UK Warehouse Association

Re-iterated previous points of the first representative of UK Warehouse Association but also said:

- Local Authority Acts do affect the incidence of buildings between counties. The more rigorous the limitations, the more resistance to locate warehouses in those areas.
- It is not the size of building that reduces risk of fire, but the quality of fire precaution management that determines the fire risks.
- A compartment size of 440,000 m3 would be adequate for the majority of warehousing requirements in the U.K, a limitation of 140,000 m3 would have a number of serious consequences.
- It is not the type or size of building that determines the requirement for sprinklers but the nearness of fire-fighters, the type of products stored, the handling characteristics and the effectiveness of management systems

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A.5 Questionnaire completed by X

Q1. Have you seen a growth in the compartment size of single storey warehouses buildings? It would be helpful if you could say what a 'typical' size would be (in terms of both floor area and height), and what a maximum size could be.
I would say that over the last 15 years warehouse footprint size has grown, to quote a typical size is difficult as the final size is dependent on the customer's requirements, the trend in say the retail sector has been to go for fewer but larger Regional distribution centres (RDC) customers with fewer point of sale outlets or manufacturers may go for one National distribution centre (NDC). The result is that typically 30,000 to 40,000 m^2 buildings can be required to fulfil these requirements, (even larger buildings are not uncommon) but anything from say 10,000 m^2 are still required. Height, whilst again can vary dependant on the operation, can, more than the footprint be said to have a more typical approach to it, I would say that 11.5 to 12 m clear height to underside of the structural haunch is fairly common. This would typically give a top of product height in the region of 10.5 m. This is primarily affected by two factors: the choice of mechanical handling equipment, and the preference of operators to install a higher specification ESFR roof only sprinkler system, which has stringent product and building height constraints, which can generally be accommodated within the heights quoted above, rather than a roof and in rack installation. These product heights allow the operator a wide choice of relatively standard MHE equipment, Reach trucks, etc. as heights start to substantially increase the MHE becomes more specialist and costly. In rack sprinkler systems can be susceptible to impact damage during the operation of the facility, if damaged stock loss can result from water penetration, and the operation halted in that area of the warehouse until repairs and the clean up has been completed. It reduces flexibility in terms of racking alterations, and increases the cost of those alterations. The ESFR roof only system is not accessible to operational impact damage, and full flexibility is maintained, whilst ensuring a very efficient fire fighting capability. Buildings are being constructed to say 32 m high, but these are automated operations with very few, and sometimes no personnel within the warehouse.

Q2. What factors are causing this growth in warehouse compartment size?
Efficiency of operation, and cost, I am aware over the years clients have moved from over 20 smaller warehouses to say 5 RDCs, which are strategically placed to serve their outlets or manufacturing bases.

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Q3. Have you any experience of Local Authority Acts and their limitations of compartment size? Have they ever resulted in a warehouse being constructed in an adjacent LA area where limitations are not as stringent?
Yes, The old Manchester Fire Act, Berkshire Act, but I have to date not been involved in moving a location because of these particular requirements. If the location is critical in terms of serving the customer requirements, then that is where it is placed.

Q4. Do you think a national limit on compartment size would reduce fire risks (in terms of life, injury, property and contents)?
The first and foremost objective is to preserve life. I do consider there is a distinction to be made between buildings that are accessible to the public, and those only occupied by an "educated" workforce, i.e. within private single storey warehouses the current regulations. Re: escape distances, signage, fire detection, fire protection etc. and the on site management safety practices mean that within a very short space of time the operatives are fully aware of what to do, where to go, should an incident occur, they become an "educated " workforce, dealing with a cash and carry type warehouse full of shoppers will bring a host of different problems. A limit on compartment size should however reduce the risk of Maximum Foreseeable Loss (MFL) in terms of the property and stock. So, in large, modern, single storey warehouses, with an "educated workforce" it is a difficult question to answer, personally, if we compartment and initially people are allowed to escape from one compartment to another, and by this we can eliminate risk to life then we should consider implementing a national limit, as long as the limit is sensible and workable.

Q5. Do you think there would be any other positive benefits? E.g. in terms of reduced environmental impact, removal of local distortions, reduced insurance premiums.
It would certainly eliminate the current uncertainty as to "should we or shouldn't we", also the anomalies between Local area and Fire Officer interpretations and recommendations. With regard to insurance, any benefit, whilst deemed by the insurers to be a "better" risk, would not be achieved overnight, and many large companies are able to negotiate competitive property premiums, and take a reasonable deductible, therefore the benefit to these large companies may not be as evident. However, from a risk management, and continuation of business following loss point of view, the introduction of this type of legislation may offer savings from the uninsured loss position.

Q6. What would be the impact of the proposed requirement on compartment size (of 140,000 m^3) in terms of building costs? Can you quantify this in terms of a % increase and/or actual sum?
Again. difficult to be totally precise due to the internal operational design which will differ dependent on the product being stored, and the type of operation being carried out. However, if we consider a 140,000 m^3 chamber size, I would comment as follows. Let us assume we have an average building height of 12 m, the chamber size above would equate to a chamber footprint of circa 11,600 m^2 and a total building footprint of 23,200 m^2.

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This would then require 1 fire division wall, a building of this size for RDC operations would typically be say: 232 m x 100 m, therefore the fire wall would be 100 m x 12 m (assuming it does not need to penetrate the roof).

This wall would need at least three 5 m high fire doors for the passage of MHE, together with personnel escape doors, the roof for say 2 m each side of the wall would need fire protection, and the wall would have impact protection along its base, and around the doors. If we assume we need two hours fire rating, let us also assume we construct the wall with concrete blocks with steel restraints.

I estimate that this construction would be in the region of £185k to £205k.

A knock on effect of inserting this wall over the same building without a fire wall could be an increase in rental, i.e. the building would be the width of the wall and its protection, say 600 mm, longer, therefore the building footprint would be about 650ft^2 larger, if we assume the rental to be £5.25 per ft^2 that equates to £3,400 per annum extra, until the first rent review.

A chamber size of 11,600 m^2 may seem reasonable for a standard height building, however, a 32 m high bay unit would have its footprint reduced to 4,375 m^2. In terms of the type of operation this would be, and the minimal number of staff (if any) employed within the unit, this may be considered too small to be viable.

Q7. What would be the impact of the proposed requirement in terms of operational costs (e.g. rental, handling, transport movements etc)? Can you quantify these?

If the proposal were to be adopted, as long as the fire wall position was known, the operation could be designed around it, therefore the operational impact would I think be minimal, in a fully racked warehouse, a blocked stack operation where the MHE has a more roving role may be different, (although I am not an Operator). The rental and capital cost impact I have attempted to quantify in the section above.

Q8. Have you any alternative suggestions for improving fire safety in such buildings?

If we assume we are dealing with a modern single storey warehouse, with escape routes, fire alarms, smoke detection, sprinklers etc. and these elements have been designed, and fitted to the correct standard, maintained as necessary, then if an incident should occur we are reliant on three things:

1, The good management housekeeping within and around the building, i.e. escape routes kept clear, Safe working practices, especially when dealing with MHE battery changing, rubbish and debris collected regularly and contained in proper areas, and removed from site at regular intervals. STRICT NO SMOKING POLICY.
2, Good, clear, and regularly updated training of all staff on what to do in an alarm incident, clear signage, Reminders on the warehouse communication board.
3, Reliance on the staff to react in the way they have been trained, not only in how to get out, but how by being vigilant and observant to spot a potential incident before it becomes one.

If we follow these simple rules even if we suffer say equipment failure which results in a fire, the question of the occupant's safety should not be an issue.

One final point, a single storey warehouse without compartmentation has a small advantage, i.e. that the occupants whilst moving about the floor are more likely to spot an incident early, and be able to raise the alarm, than if that incident were behind a fire wall in a compartment which at that time was not occupied.

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A.6 Questionnaire completed by Y

Q1. Have you seen a growth in the compartment size of single storey warehouses buildings? It would be helpful if you could say what a 'typical' size would be (in terms of both floor area and height), and what a maximum size could be.

For us typical buildings are now 100-750,000 ft sq at 10-12m high.

Q2. What factors are causing this growth in warehouse compartment size?

Consolidation of client businesses into single DCs, amalgamation of businesses, emergence of 'dominant' players (like Tesco).

Q3. Have you any experience of Local Authority Acts and their limitations of compartment size? Have they ever resulted in a warehouse being constructed in an adjacent LA area where limitations are not as stringent?

We have experience of Local Acts and have installed sprinklers solely because of the act and not for business reasons, I am not aware that we have knowingly selected an alternate LA area just for this reason but we may have selected an unsprinklered option due to cost.

Q4. Do you think a national limit on compartment size would reduce fire risks (in terms of life, injury, property and contents)?

Life and injury - probably not as long as existing escape rule are applied, Property and contents possibly if fires like the recent Primark example are contained.

Q5. Do you think there would be any other positive benefits? E.g. in terms of reduced environmental impact, removal of local distortions, reduced insurance premiums.

So far we have not seen much difference in insurance premiums - certainly not enough to justify sprinklers on its own. If local distortions were eliminated by removing the requirement for sprinklers then I would consider it an advantage, in the current environment compulsory sprinklers would in most cases just impose an additional economic burden. Our normal policy is to perform a proper risk evaluation and decide if sprinklers are justified. Assuming that our policy is to prevent the outbreak of fire in the first instance the impact on the environment is also negligible - if all building were sprinklered there would be an additional demand on the water supply which is already inadequate at a number of our sites, cost of renewing water mains to service this 'new'; requirement would be prohibitive.

Q6. What would be the impact of a proposed requirement on compartment size (of 140,000 m^3) in terms of building costs? Can you quantify this in terms of a % increase and/or actual sum? Is there a compartment size limit that would be appropriate (440,000 m^3)?

I can't comment on increased cost as I have no information. I have no view on a size limit other than it should be as large as feasible.

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Q7. What would be the impact of the proposed requirement in terms of operational costs (e.g. rental, handling, transport movements, etc)? Can you quantify these?

The smaller the compartment and the fewer the access points between the compartments the longer travel distances become requiring more handling equipment and associated staff - penalty could be 5-10%. Smaller compartments make it less possible to layout the operation efficiently and typically impose some penalty in additional space - say up to 5% - which impacts rental.

Q8. Have you any alternative suggestions for improving fire safety in such buildings?

Proper control and management of fire risks - smoking policies, electrical testing, etc. Proper Risk assessment and appropriate awareness and reaction training

Q9. What size/type of building is likely to have sprinkler protection installed voluntarily? What proportion of buildings are likely to have sprinkler protection?

For us there is no relation between size and sprinklers we have small and large buildings both with and without sprinklers 0- the key determinant is risk. Approximately 50% of our buildings have sprinklers.

A.7 Questionnaire recorded by BRE following telephone interview with Z

Q1. Have you seen a growth in the compartment size of single storey warehouses buildings? It would be helpful if you could say what a 'typical' size would be (in terms of both floor area and height), and what a maximum size could be.

Yes. Most new builds are 12 m to the eves, older buildings are 6 m, 9 m, 10 m. 12 m eve height is to some extent the limit for a standard warehouse as this is the limit of the mechanical handling equipment.

There are a range of building shapes, layouts, floor area, perhaps typical area would be 25,000 m^2. Application of the 45 m travel distance, to some extent, limits the floor area.

Q2. What factors are causing this growth in warehouse compartment size?

Customer demand

Economics (management overhead for a larger site is a smaller percentage)

Q3. Have you any experience of Local Authority Acts and their limitations of compartment size? Have they ever resulted in a warehouse being constructed in an adjacent LA area where limitations are not as stringent?

Has experience of local acts, but not seen warehouse problems because of the Acts.

Where sprinklers are required they can represent a significant cost (say £400,000 for 15,000 m^2 building).

Developers will generally build new warehouses with no sprinklers and the tenant (customer) will/may select sprinklers for their needs (the system design is hazard dependent, OH, ESFR). Tenant (customer) can be on short term contracts, so the system requirements can change at the end of the contract (hazard class, US versus UK) thus making the systems expensive and in some cases redundant.

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Q4. Do you think a national limit on compartment size would reduce fire risks (in terms of life, injury, property and contents)?

It could reduce fire losses and the effect of a fire, not risk. Fire risk would be better dealt with by addressing escape routes, fire loads, management and security (in particular fires caused by electrics and arson).

Imposing a compartment size is not a practical solution.

Q5. Do you think there would be any other positive benefits? E.g. in terms of reduced environmental impact, removal of local distortions, reduced insurance premiums.

In principle yes, in reality, probably no benefit from insurers.

It should be noted that as soon a you put a door or shutter in a compartment wall, its presence is largely ignored by insurers.

Limiting compartment size and therefore imposing sprinklers, will add another problem, preparation for fire water from chemical warehouses. Regulations in France and Europe may be of interest here.

Q6. What would be the impact of a proposed requirement on compartment size (of 440,000 m^3) in terms of building costs? Can you quantify this in terms of a % increase and/or actual sum? Is there a compartment size limit that would be appropriate (140,000 m^3)?

It would have a significant economic and commercial impact, and would have a significant impact on the business operations (e.g. movement through doors).

Q7. What would be the impact of the proposed requirement in terms of operational costs (e.g. rental, handling, transport movements etc)? Can you quantify these?

Not easy to quantify, there would be a capital cost.

Q8. Have you any alternative suggestions for improving fire safety in such buildings?

The fire engineering approach works well, escape strategies, smoke control etc. (novel solutions, e.g. tunnels for escape).

Q9. What size/type of building is likely to have sprinkler protection installed voluntarily? What proportion of buildings are likely to have sprinkler protection?

You cannot generalise, very dependent on the customer, in the 12,000 m^2 category, perhaps 20% are sprinklered. They have no warehouses quite as big as 440,000 m^3.

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A.7 Answers to questionnaire completed by second representative of UK Warehouse Association

Note. The writer has built and operated warehouses with an aggregate in excess of 1,000,000 sq.ft (93,000 m^2), ranging from 20,000 sq.ft.(1850 m^2) to 250,000 sq.ft.(23,000 m^2) and from 20 ft (6m) to eaves to 60 ft.(18 m).to eaves. Some were racked, some, not all, were equipped with sprinklers.

Q1 and Q2. The size of buildings has increased and continues to increase, as a result of the requirement to reduce the number of stockholding points throughout the UK.

There is no such thing as a typical size of building. The range of sizes within the industry is from 5,000 sq.ft. to 300,000 sq.ft or more. Similarly, heights range from 12 ft. to 60 ft or more.

Q3. Limitations on compartment size vary from local authority to another and from one Fire and Rescue Service to another. Some L.A.s impose inconsistent arbitrary limitations on compartments, whilst sprinklers are mandatory in some counties but not in others. This affects the incidence of buildings between counties. The more rigorous the limitations, the more resistance to locate warehouses in those areas.

Q4. It is not the size of building that reduces risk of fire, but the quality of fire precaution management that determines the fire risks. Poor management in small buildings creates far greater risks then good management in larger buildings.

Q5.

1. Environmental Impact – More fuel usage – see Q7

2. Removal of local distortions. All other things being equal, a national limit on compartment size would allow buildings to be constructed in their optimum locations, rather than the dictats of L.A.s.

3. Reduced Insurance Premiums – Reduction in premiums are usually insignificant in relation to the capital costs of buildings.

Q6. The impact of imposing a limitation of 140,000 m^3 would have a number of serious consequences viz,

1. Capital costs would be increased by a minimum 10% assuming that only one partition wall on the short elevation were to be erected. As the number of partition walls increased the capital costs would increase pro rata, thus increasing depreciation and rentals.

2. Access to every part of a warehouse building would normally be necessary, therefore, it would also be necessary to incorporate fusible-link doors in each partition wall as part of the precautions to prevent the spread of fire from one compartment to the next. Construction costs would increase accordingly.

3. Similarly, if sprinklers were incorporated, access for pipework between compartments would be unnecessary, at additional costs.

4. A compartment size of 440,000 m^3 would be adequate for the majority of warehousing requirements in the U.K.

Large building contractors could supply accurate estimates for all of these costs.

Q7 Warehouses that are used for the storage of fast-moving products, such as mail order, fmcg, car parts etc which require intensive handling activities, would probably require multi-access points between each compartment, thus increasing the necessity of additional fusible-link doors and more sprinkler pipework.

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Importantly, the restriction of accesses between storage areas created by compartmentation would greatly increase travelling times of all handling equipment such as fork trucks and AGVs. Additional equipment costs and labour costs would be incurred accordingly.

Q8. As in the previous questions, several books can be written on each of the subjects you have mentioned. A start could be made, by adopting the Regulatory Reform (Fire Precautions) Order, currently under revision at the BRE itself.

Q9. Again, it is not the type or size of building that determines the requirement for sprinklers but the nearness of fire-fighters, the type of products stored, the handling characteristics and the effectiveness of management systems that dictate the necessity or otherwise for sprinklers. Factors, such as the possible loss of markets or information too, account for many decisions on whether or not to install sprinklers.

The governing factor as far as the third party provider is concerned is whether an economic return in terms of rental and handling charges can be obtained from its customers. Only the customer can determine whether to take the risk of not specifying sprinklers as part of the warehousing contract. That is the reason why it is only long term contracts that usually attract the inclusion of a sprinkler installation in new buildings. The roofs of existing buildings, rarely being strong enough to support sprinklers as a later addition.

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Appendix B – Cost benefit analyses

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**100**			
Purchase Cost of Sprinklers (per sq.m)	£34.60		£9.50	£44
Purchase Cost of Sprinklers (per building)	£3,460		£950	
Cost of Water Supplies (per building)	£37,400		£6,000	£281
Total Capital Cost (per building)	£40,860			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£222
Annual Cost of Loan	£162			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£1,287**	**+/-**		**£521**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	3.1		1.9	£61
Sprinkler Effectiveness Factor	0.50		0.50	£99
Injuries saved per Thousand Buildings	1.6			
Monetary Value per Injury Saved	£64,102		£3,205	£5
Monetary Benefit per Single Building	£99			
Fires per Thousand Buildings (store area)	59		20	£275
Sprinkler Effectiveness Factor	0.85		0.10	£95
Unsprinklered property damage (sq.m)	77		15	£158
Reduced property damage per fire (sq.m)	65			
Monetary Benefit per sq.m	£210		£150	£579
Monetary Benefit per Fire	£13,745		£10,304	£43
Monetary Benefit per Building	£811			
Fires per Thousand Buildings (other area)	14		4	£14
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£19
Reduced property damage per fire (sq.m)	£4,123			
Monetary Benefit per Building	£58			
Total Monetary Benefit per Building	**£968**	**+/-**		**£679**
Benefit : Cost ratio	**0.75**	**+/-**		**0.61**
Confidence Level: pr(ratio > 1)	**21%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**300**			
Purchase Cost of Sprinklers (per sq.m)	£34.60		£9.50	£133
Purchase Cost of Sprinklers (per building)	£10,380		£2,850	
Cost of Water Supplies (per building)	£37,400		£6,000	£281
Total Capital Cost (per building)	£47,780			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£260
Annual Cost of Loan	£486			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£1,611**	**+/-**		**£552**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	0.9		0.6	£19
Sprinkler Effectiveness Factor	0.50		0.50	£29
Injuries saved per Thousand Buildings	0.5			
Monetary Value per Injury Saved	£64,102		£3,205	£1
Monetary Benefit per Single Building	£29			
Fires per Thousand Buildings (store area)	10		3	£140
Sprinkler Effectiveness Factor	0.85		0.10	£55
Unsprinklered property damage (sq.m)	261		63	£112
Reduced property damage per fire (sq.m)	222			
Monetary Benefit per sq.m	£210		£150	£333
Monetary Benefit per Fire	£46,589		£35,551	£149
Monetary Benefit per Building	£466			
Fires per Thousand Buildings (other area)	14		4	£49
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£65
Reduced property damage per fire (sq.m)	£13,977			
Monetary Benefit per Building	£196			
Total Monetary Benefit per Building	**£690**	**+/-**		**£420**
Benefit : Cost ratio	**0.43**	**+/-**		**0.30**
Confidence Level: pr(ratio > 1)	**0%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**1000**			
Purchase Cost of Sprinklers (per sq.m)	£32.30		£9.00	£421
Purchase Cost of Sprinklers (per building)	£32,300		£9,000	
Cost of Water Supplies (per building)	£40,400		£5,000	£234
Total Capital Cost (per building)	£72,700			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£396
Annual Cost of Loan	£1,513			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£2,638**	**+/-**		**£728**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	1.1		0.7	£22
Sprinkler Effectiveness Factor	0.50		0.50	£35
Injuries saved per Thousand Buildings	0.6			
Monetary Value per Injury Saved	£64,102		£3,205	£2
Monetary Benefit per Single Building	£35			
Fires per Thousand Buildings (store area)	6		2	£288
Sprinkler Effectiveness Factor	0.85		0.10	£102
Unsprinklered property damage (sq.m)	807		227	£243
Reduced property damage per fire (sq.m)	686			
Monetary Benefit per sq.m	£210		£150	£617
Monetary Benefit per Fire	£144,050		£111,874	£470
Monetary Benefit per Building	£864			
Fires per Thousand Buildings (other area)	14		4	£151
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£202
Reduced property damage per fire (sq.m)	£43,215			
Monetary Benefit per Building	£605			
Total Monetary Benefit per Building	**£1,505**	**+/-**		**£905**
Benefit : Cost ratio	**0.57**	**+/-**		**0.38**
Confidence Level: pr(ratio > 1)	**1%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**3000**			
Purchase Cost of Sprinklers (per sq.m)	£32.30		£9.00	£1,264
Purchase Cost of Sprinklers (per building)	£96,900		£27,000	
Cost of Water Supplies (per building)	£40,400		£5,000	£234
Total Capital Cost (per building)	£137,300			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£747
Annual Cost of Loan	£4,538			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£5,663**	**+/-**		**£1,534**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	1.4		0.9	£29
Sprinkler Effectiveness Factor	0.50		0.50	£45
Injuries saved per Thousand Buildings	0.7			
Monetary Value per Injury Saved	£64,102		£3,205	£2
Monetary Benefit per Single Building	£45			
Fires per Thousand Buildings (store area)	6		2	£1,029
Sprinkler Effectiveness Factor	0.85		0.10	£363
Unsprinklered property damage (sq.m)	2883		1179	£1,263
Reduced property damage per fire (sq.m)	2451			
Monetary Benefit per sq.m	£210		£150	£2,205
Monetary Benefit per Fire	£514,616		£427,869	£1,797
Monetary Benefit per Building	£3,088			
Fires per Thousand Buildings (other area)	14		4	£540
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£720
Reduced property damage per fire (sq.m)	£154,385			
Monetary Benefit per Building	£2,161			
Total Monetary Benefit per Building	**£5,294**	**+/-**		**£3,420**
Benefit : Cost ratio	**0.93**	**+/-**		**0.65**
Confidence Level: pr(ratio > 1)	**42%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**10000**			
Purchase Cost of Sprinklers (per sq.m)	£31.20		£9.25	£4,332
Purchase Cost of Sprinklers (per building)	£312,000		£92,500	
Cost of Water Supplies (per building)	£44,400		£4,000	£187
Total Capital Cost (per building)	£356,400			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£1,940
Annual Cost of Loan	£14,610			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£15,735**	**+/-**		**£4,765**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	1.0		1.2	£38
Sprinkler Effectiveness Factor	0.50		0.50	£32
Injuries saved per Thousand Buildings	0.5			
Monetary Value per Injury Saved	£64,102		£3,205	£2
Monetary Benefit per Single Building	£32			
Fires per Thousand Buildings (store area)	10		5	£6,452
Sprinkler Effectiveness Factor	0.85		0.10	£1,518
Unsprinklered property damage (sq.m)	7229		4460	£7,961
Reduced property damage per fire (sq.m)	6145			
Monetary Benefit per sq.m	£210		£150	£9,217
Monetary Benefit per Fire	£1,290,377		£1,227,340	£5,155
Monetary Benefit per Building	£12,904			
Fires per Thousand Buildings (other area)	14		4	£1,355
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£1,807
Reduced property damage per fire (sq.m)	£387,113			
Monetary Benefit per Building	£5,420			
Total Monetary Benefit per Building	**£18,355**	**+/-**		**£14,965**
Benefit : Cost ratio	**1.17**	**+/-**		**1.01**
Confidence Level: pr(ratio > 1)	**63%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**30000**			
Purchase Cost of Sprinklers (per sq.m)	£31.20		£9.25	£12,995
Purchase Cost of Sprinklers (per building)	£936,000		£277,500	
Cost of Water Supplies (per building)	£44,400		£4,000	£187
Total Capital Cost (per building)	£980,400			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£5,337
Annual Cost of Loan	£43,830			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£44,955**	**+/-**		**£14,054**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	2.0		3.4	£109
Sprinkler Effectiveness Factor	0.50		0.50	£64
Injuries saved per Thousand Buildings	1.0			
Monetary Value per Injury Saved	£64,102		£3,205	£3
Monetary Benefit per Single Building	£64			
Fires per Thousand Buildings (store area)	16		15	£50,881
Sprinkler Effectiveness Factor	0.85		0.10	£6,385
Unsprinklered property damage (sq.m)	19003		23710	£67,716
Reduced property damage per fire (sq.m)	16153			
Monetary Benefit per sq.m	£210		£150	£38,766
Monetary Benefit per Fire	£3,392,036		£4,892,997	£20,551
Monetary Benefit per Building	£54,273			
Fires per Thousand Buildings (other area)	14		4	£3,562
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£4,749
Reduced property damage per fire (sq.m)	£1,017,611			
Monetary Benefit per Building	£14,247			
Total Monetary Benefit per Building	**£68,583**	**+/-**		**£95,788**
Benefit : Cost ratio	**1.53**	**+/-**		**2.18**
Confidence Level: pr(ratio > 1)	**68%**			

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PROPERTY TYPE: Warehouse

	average		uncertainty	net effect
Building Area (sq.m)	**100000**			
Purchase Cost of Sprinklers (per sq.m)	£31.20		£9.25	£43,315
Purchase Cost of Sprinklers (per building)	£3,120,000		£925,000	
Cost of Water Supplies (per building)	£44,400		£4,000	£187
Total Capital Cost (per building)	£3,164,400			
System lifetime (years)	40		10	
Discount rate	3.5%		0%	
Capital Recovery Factor	0.047		0.005	£17,226
Annual Cost of Loan	£146,101			
Annual Maintenance Cost	£1,125		£375	£375
Total Annual Cost	**£147,226**	**+/-**		**£46,617**
Deaths per Thousand Buildings	0.0		0.0	£0
Sprinkler Effectiveness Factor	0.50		0.50	£0
Deaths saved per Thousand Buildings	0.0			
Monetary Value per Death Saved	£1,366,693		£68,335	£0
Monetary Benefit per Single Building	£0			
Injuries per Thousand Buildings	14.2		24.3	£779
Sprinkler Effectiveness Factor	0.50		0.50	£455
Injuries saved per Thousand Buildings	7.1			
Monetary Value per Injury Saved	£64,102		£3,205	£23
Monetary Benefit per Single Building	£455			
Fires per Thousand Buildings (store area)	90		192	£1,918,786
Sprinkler Effectiveness Factor	0.85		0.10	£105,815
Unsprinklered property damage (sq.m)	55987		87645	£1,408,017
Reduced property damage per fire (sq.m)	47589			
Monetary Benefit per sq.m	£210		£150	£642,451
Monetary Benefit per Fire	£9,993,680		£17,236,380	£72,393
Monetary Benefit per Building	£899,431			
Fires per Thousand Buildings (other area)	14		4	£10,493
Benefit (other fire) / Benefit (store fire)	0.30		0.10	£13,991
Reduced property damage per fire (sq.m)	£2,998,104			
Monetary Benefit per Building	£41,973			
Total Monetary Benefit per Building	**£941,860**	**+/-**		**£2,468,550**
Benefit : Cost ratio	**6.40**	**+/-**		**16.89**
Confidence Level: pr(ratio > 1)	**74%**			

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