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The Value of Fire Protection in Buildings

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THE VALUE OF FIRE PROTECTION IN BUILDINGS

by

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SUMMARY INSERT TO //

This report describes a study of the value of sprinklers, detectors and improved internal structural fire protection in reducing property damage in buildings. The value is considered mainly from the point of view of the national economy, and the value is calculated by comparing the cost of providing the fire protection with the expected future savings in fire losses.// The value of fire protection from the firms' point of view is considered briefly.

The study has been undertaken as a statistical exercise, using data from brigade fire reports, and also the detailed information from a special survey of fires. The value of the fire protection measures is estimated for buildings in different occupancies and of different sizes.

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THE VALUE OF FIRE PROTECTION MEASURES IN BUILDINGS

1. INTRODUCTION

1.1 The objective of the study

The objective of this study is to produce an overall picture of the value to the national economy of installing various fire protection measures in buildings. The fire protection measures considered are sprinklers, automatic detectors with local alarms, automatic detectors with direct line alarms, and increased fire resistance in the internal structure of a building.

In this study only the protection of property is considered. The value of fire protection measures in protecting life is the subject of a separate study.

The key words in the statement of the objective are the requirements to produce an overall picture from the point of view of the national economy. These two requirements have dictated the form of the study.

This study was undertaken for the Home Office Fire Department and it is the responsibility of central government to consider the national economic consequences of fire and of fire protection. The analysis is therefore expressed in terms of the effects on the national economy. The fire losses considered are the direct and consequential losses to the national economy. Similarly, the costs of providing fire protection are considered from the national economy point of view. These costs may be quite different to the costs experienced by the owners or occupiers of the buildings.

While the primary objective of the study has been to consider the costs to the national economy, it is also of some interest to consider the costs and benefits from the firm's point of view. The value of fire protection to an individual firm has therefore also been estimated and the two different points of view are compared in this study.

The most difficult requirement to meet is that of providing an overall picture. A conflict arises here. If all the factors which might determine the value of the fire protection measures in a building are included then the final results would be far too detailed to provide an overall and understandable picture (and the time taken to do such a study would be beyond the allowable time scale). On the other hand, if too many simplifications and generalisations are made then the results may become oversimplified to the point of being meaningless.

The conflict is between manageability and complexity. But as this study is concerned with the broad issues of fire protection strategy, we have deliberately chosen an approach which is well towards the simple and manageable end of the scale. In the simplifications and generalisations we have made in presenting the results we have ignored the detailed circumstances of individual buildings and have attempted to produce results only for broadly defined classes of buildings. The results therefore only apply to the buildings as a class or to the typical or average buildings within each class. Within each class of buildings there may well be some buildings in which the circumstances are different from the "typical" building and for which the general answer is not valid. However, although the results are not sufficiently detailed to provide reliable answers for individual buildings, this does not invalidate the overall picture or the general conclusions.

1.2 The degree of detail considered in the study

The starting point for this study was a detailed examination of a large number of individual fires. When the individual fires were examined each fire was treated as a unique case, and the effect of fire protection measures was assessed for that fire in that building, taking into account all the relevant circumstances of the fire and building. The information from the examination of the individual fires was then used to produce the overall results, and at this stage some simplifications and generalisations had to be made. A number of broad classes of buildings were specified and the individual results were then aggregated and summarised to provide estimates of the effect of fire protection in each class of buildings.

In this study results have been derived for classes of buildings defined by the occupancy and the size of the building. The main occupancy groups considered are industrial, storage and shops. The industrial group is further subdivided and different sectors of industry are considered separately. Other occupancies, including offices, hospitals, schools and places of public assembly have also been considered but only a limited amount of data was available for these occupancies and the results are therefore less reliable.

It is recognised that there are many other factors which will determine the value of fire protection in a building. These additional factors include the specific activity or process which takes place in the building, the design and materials of construction of the building, the nature of the contents, the fire-fighting ability of the occupants, the proximity of the public fire brigade, the standard of housekeeping and the attitude of the management towards fire prevention. All these additional factors are beyond the limits of detail which we have considered in presenting our results.

1.3 The form of the report

Part I of this report includes a general description of the method of analysis and also an account of two topics (the probability of fire, and the estimation of fire losses) which are common to the analysis of both sprinklers and detectors. The analysis of sprinkler systems is then described in Part II, the analysis of detectors in Part III, and the evaluation of structural fire protection in Part IV. The final part, Part V, contains the main results and the conclusions.

This report is intended to provide a complete account of the study and therefore includes a large amount of technical detail. A summary account of this study, with most of the technical detail omitted, is given in Research Report 17/78.

PART I

- GENERAL CONSIDERATIONS

2. THE GENERAL APPROACH TO THE PROBLEM

2.1 The fire protection measures considered

In this study four levels of fire protection are defined and each of the four levels of protection are compared with a basic or minimum level of fire protection. The levels of fire protection considered are:

Level A (Basic protection only). This is the minimum level of fire protection required by the legislation relevant to the particular building. There must be adequate means of escape, a manually operated alarm system, well maintained fire extinguishers or other first aid fire fighting equipment and staff trained to use this equipment. This is the level of protection which is found in the majority of buildings.

Level B (Sprinkler protection). This level is defined as the basic level of protection, plus a sprinkler system. The sprinkler system is assumed to comply with the 29th edition FOC rules[1], and to be well maintained. No automatic alarm, other than that which is part of the sprinkler system, is assumed to be installed and the sprinkler alarm sounds locally only.

Level C (Automatic detection with local alarm). This level is defined as the basic level of protection, plus an appropriate form of automatic detection (heat, smoke or some other form) with a local alarm only. The detectors are assumed to comply with 11th edition[2] FOC requirements and Code of Practice CP 1019 and to be well maintained. This study is only concerned with the concept of early detection and not with the technical differences between various types of detectors.

Level D (Automatic detection with a direct line alarm). This level is defined as the basic level of protection, together with an appropriate form of automatic detection. If there is 24 hour manning on the site then the alarm will sound at some manned point. If there is not 24 hour manning then it is assumed that the detectors are connected to a central alarm station. Once again it is assumed that the detector system complies with FOC requirements and is well maintained.

Level E (Improved fire resistance). This level is defined as the basic level of fire protection, with no changes in the internal structure of the buildings, but with all existing internal surfaces (walls, ceilings, floors, doors, windows etc) upgraded to have 30 minutes fires resistance if they do not already have this resistance. It is assumed that there are no fire protection measures other than those provided in the basic level 'A'.

Only the four additional levels of fire protection defined above were assessed in this study. It was beyond the scope of the study to consider other means of fire protection such as combinations of these basic measures, or the installation of protection measures in only part of the building, or specialist protection measures such as CO_2 flooding, drenchers etc. If particular expensive or hazardous machines or contents are protected by special devices this may well change the value of any general protection in the remainder of the building.

2.2 The occupancy groups considered

The occupancy group is defined according to the main purpose for which the building is used. There is no precise means of defining the usage of a building and a common-sense judgement is made in each case. A building is often used for more than one purpose, for example a factory may include a storage area and offices. In these cases the whole of the building would be classified according to the major use of the building.

From the point of view of fire protection requirements the occupancy of the building is the single most important characteristic. The risk of fire, the type of fire which may occur and the nature, combustibility and value of the contents will be strongly related to the usage of the building.

The occupancy groups considered in this study are:

1. Industrial. These are the buildings in which the major activity is manufacture, processing or repair. There will often be storage areas and offices in these buildings. The industrial group is further sub-divided according to the type of industry as defined by the Standard Industrial Classification[3]. In this more detailed classification only the ten largest industrial groups have been considered.

2. Storage. The storage group includes buildings in specific industries where the principal use of the building is for storage.

The group also includes warehouses in wholesale and retail distribution and in the transport industry. Indoor car parks, usually classified as storage, have been excluded. Agricultural storage buildings have also been excluded.

3. Shops. All shops are considered in a single group. Laundrettes and fish and chip shops have been excluded.

4. Offices. Buildings used primarily as offices.

5. Hotels, hostels, boarding houses, etc, residential clubs, and public houses with residential accommodation attached.

6. Hospitals, nursing homes, sanatoria, children's homes, old peoples homes.

7. Places of public assembly including public houses, non-residential clubs, cinemas, restaurants, cafes, etc.

8. Schools, colleges and other educational establishments.

2.3 The basic cost-benefit equation

Each of the four levels of additional protection are assessed by estimating the fire damage which might occur in a building provided with the specified level of protection, and comparing this with the fire damage which might occur in the same building if it had only the basic level of protection.

If the probability of a fire occurring in a year is p, if L_A is the (average) loss incurred in a fire if only basic protection is provided, and if L_B is the (average) loss incurred in a fire if the fire protection is provided, then the expected reduction in the average annual fire loss due to the additional fire protection will be $p \times (L_A - L_B)$.

This reduction in fire loss (including consequential losses) must be compared with the cost of installing and maintaining the fire protection, or more exactly, with the annual equivalent cost of providing protection. If the benefits (the reduction in fire losses) exceed the costs (the costs of providing protection) then the installation of additional fire protection can be said to be justified in cost effectiveness terms. The economic interpretation of the results is discussed more fully in section 9.

Having established that the value of fire protection (as defined in this study) depends on the probability of fire, the likely fire damage and the cost of installing fire protection, the further sections of the report describe how these separate elements of the problem are determined.

2.4 Our approach to the problem

If the effect of, say, sprinklers is estimated by comparing the fire losses in fires where sprinklers were installed with the fire losses in fires where sprinklers were not installed, the results may be very misleading. This is because sprinklers may tend to be installed in larger buildings, or where the fire loading is high, or the contents are particularly valuable. It is not valid to compare fires in these buildings with fires in buildings where the circumstances may be quite different.

A simple example can be used to illustrate the pitfalls of comparing fires in sprinklered and non-sprinklered buildings. It is estimated that the average damage in the fires which occurred in sprinklered buildings in 1973 was £9,000 and the estimated average fire damage in all unsprinklered buildings in 1973 (excluding domestic property) was £2,500. It would be dangerous to draw any conclusions about the value of sprinklers by comparing these two figures!

The example given here is admittedly naive, and some of the differences between the sprinklered and non-sprinklered fires can be taken into account in the analysis. However we have tried to use a different approach in this study in order to avoid the possible bias which may result from comparing two groups of fires which are not equivalent.

Ideally, in a scientific experiment the effect of a particular factor can be determined by running a series of controlled experiments in which the factor of interest can be varied at will. The experiments are first run without the factor present. The experiments are then repeated <u>under identical conditions</u>, except that the factor is now included. A comparison of the two sets of results provides a valid like-with-like comparison and an unbiased measure of the effect of the factor.

This experimental approach obviously cannot be applied in this study of fire protection measures. However we have attempted to follow this general principle by considering a series of hypothetical experiments.

We have first attempted to estimate the fire damage which would occur in a class of buildings if all the buildings had only the basic level of fire protection. We have then estimated the damage assuming that the same fires had occurred in the same buildings under identical circumstances, except that the buildings were now fitted with some fire protection device. The difference between the two estimates of fire damage is a measure of the effect of the fire protection.

A diagramatic representation of the two series of "experiments" is shown in Figure 1. The estimate of fire damage without sprinkler protection for example, includes the following components:

i. The actual damage in those fires where the buildings were not sprinklered.

ii. An estimate of the damage which would have occurred in the sprinklered fires reported to the brigades if these buildings had not been sprinklered.

iii. An estimate of the damage which would have occurred in the sprinklered fires which were not reported to the brigades had these buildings not been sprinklered.

Similarly there are three components to the estimate of fire damage with sprinkler protection.

i. An estimate of the damage which would have occurred in those fires which were not sprinklered if those buildings had been sprinklered.

ii. The actual damage in the sprinklered fires reported to the brigade.

iii. The actual damage in the sprinklered fires not reported to the brigade.

Although this concept may at first sight appear to be complicated, a rigorous application of this principle is necessary to provide a valid like-with-like comparison.

In the analysis we have attempted wherever possible to produce a best estimate for each parameter. However there are some aspects of the problem where no basis exists for any reliable estimate. In these cases the figures used in the analysis amount to no more than an intelligent guess. Where these guesses have had to be made we have deliberately and consistently chosen to make an assumption which underestimates the value of fire protection. The final estimate of the value of the various fire protection measures may therefore be on the conservative side. An attempt has been made to estimate the effects of these conservative assumptions as well as the effects of inaccuracies in other assumptions and estimates. An illustration of the sensitivity of the results to the assumptions made in the analysis is shown in section 9.

2.5 The data used in the study

A particular effort has been made to cross check and validate the various parameters used in the analysis in order to make the results more reliable and to avoid undue dependence on any single source of data.

Data from a number of technical journals and published papers have been used in this study. In addition much valuable information has been obtained from discussions with people in the insurance and fire protection industries.

The main sources of large scale statistical information on fires comes from the K433 fire reports, the SAF 2 fire reports, a special fire survey, a survey of large fires and a postal survey of manufacturing industry.

i. The K433 Fire Reports A K433 report is completed for every fire attended by the public fire brigade where there is some damage to property. The reports include a description of the building involved, the cause of the fire and the damage caused by the fire.

The fire reports are coded and stored on files for analysis by computer. The original forms are also kept and an examination of some of the individual forms proved necessary for this study.

The 1970 and 1971 K433 fire reports for those brigades which took part in the SAF2 survey were used in many parts of the analysis. These fire reports were used in order to maintain consistency with other parts of the analysis where data from the SAF2 reports had to be used. These 1970-71 K433 records provided a sample of 39,000 non-dwelling fires.

These K433 data and the SAF2 data are now 7-8 years old. However there has not been a significant change in the pattern of fire incidence over the years (see Appendix A) despite the change in the number of fires. As long as the 1970-71 data on the type of fire is used in conjunction with more recent data on the total number of fires the final answer will still be valid.

ii. The SAF 2 Fire Reports The SAF 2 fire reports are additional fire reports which were completed by about half the brigades in a special data collection exercise run in 1970 and 1971. SAF 2 reports were completed for all fires in buildings which were not out on arrival and which had spread beyond the item of origin. The most valuable information on the SAF 2 forms, from the point of view of this study, is an estimate of the area damaged by fire and a record of the location of people in the building at the time of the fire.

iii. The Fire Survey Some of the essential information for this study could only be obtained by a detailed physical examination of fires. A special survey was therefore organised and about 400 non-dwelling fires were examined.

About 100 of these fires were visited, the scene of the fire was inspected and the circumstances of the fire were discussed with the brigade officers attending the fire and any other persons involved. The visits to fires were undertaken by a forensic scientist with many years experience of fire investigations, accompanied by a senior fire prevention officer. An example of the report completed on these fire visits is shown in Appendix B.

The remaining fires covered by the special survey were not visited as the fires were small and the circumstances of the fire straightforward. For these fires the K433 fire report was examined and supplementary questions were asked of the fire officer in charge of the first attendance at the fire.

The most valuable information obtained from this special survey was an assessment of the effect which various fire protection measures would have had (or did have) in the particular circumstances of the fire. The behaviour of any people involved in the fire was also recorded.

The fire survey took place in West Yorkshire, South Yorkshire and Greater Manchester. This resulted in an over-representation of fires in the textile and metal manufacturing industries compared with the national occurrence of such fires. However apart from this over-representation, which has been allowed for in the analysis, the results of the survey are in very good agreement with the national statistics with which they can be compared.

iv. <u>A Survey of Large Fires</u> There are few large fires but it is the few large fires which account for the major part of the total fire loss.

Due to the short time scale of the project and other organisational difficulties, it was not possible to wait for the large fires to occur and then visit the fire scenes. The large fires could only be assessed retrospectively by examining the very detailed fire brigade records kept for these fires. The fires included in the large fire survey were all those large fires which occurred in West Yorkshire, South Yorkshire and Greater Manchester during the period January 1976 to June 1977 and for which the brigades had prepared a detailed research report at the time of the fire. The fires which came into this category are the large loss fires for which the brigades had anticipated there might be further enquiries. These fires are not a truly representative sample of the large fires, but include the largest of the large fires together with other large fires of some particular interest.

These large fires were treated in a similar way to the fires in the special fire survey. A fire survey report was completed with estimates of the effects which fire protection measures would have had (or did have). In some cases it was possible to contact the officer who had attended the fire to ask for additional details. A total of 85 fires were covered in this survey.

The information obtained from these fires may be less reliable in some cases than the data from fires actually visited at the time of the fire. Nevertheless it was considered that the large fires are so important that they require special attention.

v. <u>The Postal Survey of Manufacturing Industry</u>

Almost all the available fire data is derived from fire brigade records and therefore covers only those fires to which the brigade were called. A special survey was therefore conducted to obtain information about fires not reported to the brigade, as well as other items of information required for the study. A separate report of the postal survey has been prepared [4].

The survey questionnaires were designed to provide answers to the following questions:-

a. What is the risk of fire in buildings of different sizes and in different industries?

b. To what extent are buildings in different industries protected by sprinkler systems or automatic detectors?

c. How many fires are not reported to the brigade, and in particular, how many fires in which sprinklers or detectors operate are not reported to the brigade?

3 THE RISK OF FIRE IN DIFFERENT OCCUPANCIES

The probability of a fire occurring is an important parameter in the calculation of the value of fire protection. An estimate of the probability of a fire occurring in a building of a given occupancy and a given size is required.

A large number of minor fires occur which are extinguished promptly, without difficulty or risk, and without the brigade being called. These minor fires can be excluded from the analysis as their effect will not only be small, but more importantly, will be constant, ie the damage caused by these fires will not change significantly if detectors or sprinklers are installed.

This study is concerned with the change in fire damage which would occur if detectors or sprinklers were installed. The fires which are considered in this analysis are therefore:

a. All those fires to which the brigade are currently called.

b. Those fires to which the brigade have not been called because detectors or sprinklers have operated and prevented the fire from developing.

The probability of a fire occurring to which the brigade is called is first estimated, and a correction can then be made for the unreported fires.

3.1 The estimation of the probability of fire in manufacturing industry

The probability of a fire is calculated by dividing the number of fires which occur by the total number of buildings at risk. The number of fires, and the type of buildings in which they occur, is known from the fire brigade statistics. The number of buildings of each type at risk was estimated from a survey of manufacturing industry. The detailed calculation is described in a separate report [4] and only a summary of the results is given here.

The probability of a fire in buildings of different sizes is illustrated in Figure 2 for the "all industry" group. There is clearly a non-linear relationship between the probability and the building size.

There are two possible explanations for the non-linearity of the probability function.

Firstly, there may be a scale effect. If a building is enlarged to double its size, some of the services such as the electricity or gas supply, the boiler, the kitchen and canteens etc would not double in size or in fire risk. The risk of fire in the larger buildings would therefore be less than twice that of the original buildings.

The second possible reason for the non-linearity is the sample composition effect. The larger buildings in the sample from which the probabilities were estimated may not just be larger scale versions of the smaller buildings. The larger buildings may tend to have different processes or different standards of fire prevention management or a different first-aid fire fighting capability. Because of this difference in character the larger buildings in the sample may have a proportionately lower fire risk than the smaller buildings.

It is impossible to identify which of the two reasons is responsible for the observed non-linearity in the probability function. But whatever the reason the non-linearity must be taken into account in the prediction equation. The probability of a fire is therefore expressed in the form $a. B^c$, where B is the total floorspace of the building in square metres and a and c are estimated parameters for each industry. The parameters a and c were estimated using statistical regression analysis. The numbers of fires used in the calculation were the numbers of fires attended by the brigades in 1973. Since 1973 there has been a slight reduction in the fire incidence.

The estimated probabilities of a fire are shown in Table 1 for industrial buildings in different sectors of industry. The power coefficient c is about 0.5 for the combined groups and for some of the individual industries. This figure is in agreement with the findings of research workers in other European countries[5]. However some of the coefficients for the separate industries are markedly different. This difference may be due to a different scale effect or a different sample composition effect, and we have no explanation for these differences.

The data collected in the survey of manufacturing industry was also used to estimate the probability of a fire in a storage building. However this estimate is regarded as unreliable because of the problems of the definition of a "storage" building.

The estimate of the probability of fire in all industrial buildings in manufacturing industry is assumed to apply to all industrial buildings.

3.2 The probability of a fire in storage buildings, shops, offices and hotels

The amount of property at risk in storage buildings, shops and offices can be estimated from the Town and Country Planning Statistics[6]. Estimates of the amount of hotel accommodation have also been published[7]. These statistics, after some slight adjustments for differences of definition, provide estimates of the total floorspace in each of these occupancies in England and Wales. There is also some information about the size distribution of premises, but the size distribution is expressed in terms of the sizes of the hereditaments or establishments, which are not necessarily the same as buildings, and the data is only subdivided into 3 or 4 size groups. This information on the size distribution is not sufficient to allow the probability of fire to be estimated for each size of buildings as was done in the case of industrial buildings. A different approach has therefore had to be used.

The probability of fire in buildings of size group i is defined as:-

$$p_i = \frac{\text{number of fires in buildings of size } i}{\text{number of buildings of size } i} = \frac{n_i}{N_i}$$

The probability function p_i is assumed to be of the form $p_i = a.\ B_i^{\ c}$ where B_i is the size of the buildings in size group i. Rearranging these two expressions, $N_i = \frac{n_i}{p_i} = \frac{n_i}{a.\ B_i^{\ c}}$.

The total building floorspace is $\sum N_i\ B_i = \frac{1}{a}\sum n_i\ B_i^{\ (1-c)}$

Now, if the power coefficient, c , is known, the multiplying coefficient a can be calculated from the equation:

$$a = \frac{\sum n_i\ B_i^{\ (1-c)}}{\text{Total building floorspace.}}$$

The probability function for storage, shops, offices and hotels was therefore calculated by trying different values of the parameter c and calculating the corresponding values of the parameter a, using the known numbers of fires n_i and the known total building floorspace. It remains then to decide on the "best" value of c. for each occupancy. The "best" value of c. was chosen by comparing the implied building size distribution (The value of $\sum n_i B_i^{(1-c)}$ summed over ranges of i.) with the distribution of hereditament sizes.

This is not a totally satisfactory way of estimating the coefficient c. But in this analysis we are concerned with the predicted probability of fire, a. B^c, and not with the parameter c on its own, and the function a. B^c is relatively insensitive to the value over a wide range of building sizes. For example, for storage buildings the assumed values of c, the corresponding values of a and the predicted probability of a fire in different size buildings are as follows:

Assumed value of c	Calculated value of a	Probability aB^c in building size:		
		500 m^2	1500 m^2	2500 m^2
0.25	0.0076	0.036	0.047	0.054
0.35	0.0035	0.031	0.045	0.054
0.50	0.00113	0.025	0.044	0.056
0.65	0.00040	0.023	0.046	0.064

It can be seen from the above figures that the predicted probability of a fire does not change markedly if c varies from 0.25 to 0.65.

In this analysis the most appropriate value of the power coefficient i appeared to be about 0.5 for storage buildings, higher for offices (c = 0.9), and a linear function (c. = 1.0) appeared to be most appropriate for shops and hotels.

The estimated probabilities of a fire are shown in Table 1. The estimated probability of a fire in a shop is similar to that in an industrial building of the same size, and much higher than the probability of a fire in a storage building or office. Hotels appear to have a higher probability of fire, for buildings of the same floorspace.

3.3 The probability of a fire in other occupancies

There is even less information available about the amount of property at risk in hospitals and schools. Estimates of the total floorspace can be obtained, but no information about the size distribution of the buildings is readily available. The power coefficient c had therefore to be set arbitrarily.

It was arbitrarily assumed in this calculation that the power coefficients for these occupancies are 0.75. This assumed value is intermediate between the value for storage and industry (c = 0.5) and offices, hotels and shops (c = 0.9, 1.0). Having assumed a value for the coefficient c, the remaining coefficient a can be calculated from a knowledge of the fire incidence and the total floorspace at risk.

The estimated floorspace in these occupancies, and the source of the information about floorspace is as follows:

Occupancy	Estimated floorspace England and Wales 1973	Source of information
Hospitals and residential institutions	Hospitals - 427,000 beds	- Annual Abstract of Statistics
	x 31 m^2/bed	- Study of plans of a sample of hospitals (Reference 8)
	Residential institutions 155,000 beds x 35 m^2/bed	- Information provided by DHSS
Schools	Primary schools 5,000,000 students x 3.7 m^2)	- Number of students is reported in the Annual Abstract of Statistics
	Secondary schools 3,900,000 students x 7.2 m^2)	
	Further, higher education 1,200,000 full-time equivalent students x 12.6 m^2)	- Average floorspace per student is based on figuree provided by DES

The probability function for hotels, hospitals and schools is shown in Table 1. No information on the floorspace in places of assembly (pubs, restaurants etc.) is available and for the purposes of this study it has been assumed that the probability of a fire in these buildings is 0.00007

B $^{1.0}$. This assumed figure was chosen as being intermediate between the probability of a fire in hotels and in shops.

3.4 The correction for unreported fires

The probabilities calculated so far apply only to the fires reported to the brigades. It was estimated in the survey of manufacturing industry[4] that about 10% of the fires in which sprinklers operated were not reported to the brigades. In manufacturing industry about 15% of the reported fires are in sprinklered buildings, and 40% of the fires in sprinklered buildings do not activate the sprinklers. The number of unreported fires which activate sprinklers is therefore equal to only .10 x .15 x .6 = 0.9% of the number of reported fires. The number of fires in buildings fitted with detectors is even less than the number in sprinklered buildings. It is therefore not worthwhile making this small correction to the estimated probability of fire to take account of these unreported fires. (Although in other parts of the analysis where the unreported fires have a greater effect a correction has been made).

4. THE RELATIONSHIP BETWEEN FIRE LOSSES AND THE AREA OF FIRE DAMAGE

4.1 Direct losses

All the available information on fire damage is in terms of the area of fire damage. This information is obtained from the SAF2 fire reports and from our own survey of fires. The estimates of the reduction in fire damage when fire protection is installed must ultimately be converted to monetary terms so that it can be used in the economic analysis. A study has therefore been made of the relationship between the fire loss and the area damaged by fire, and the full results of the study are reported separately.[9]

The study of fire losses was undertaken with the help of a firm of loss adjusters who provided detailed information on the damage and losses in a sample of 200 fires. An analysis of these detailed fire loss data showed that, if the smallest fires were excluded, the average fire loss per unit area of fire damage did not depend on the size of the fire or the proportion of the building damaged. As the small fires make a very small contribution to the total fire losses the fire losses can be predicted by assuming a constant loss per unit area of fire damage for all fires in a given occupancy. These unit loss figures were then calculated from aggregate fire loss and fire damage data so that the largest possible sample size could be used for the estimation. The estimates of the unit losses for the different occupancy groups are shown in Table 2.

The losses shown in Table 2 are the direct losses to the national economy. These losses represent the indemnity value of the property damaged (ie the depreciated value of the buildings, plant and machinery) and exclude a few losses in which assets are not replaced and are assumed to have no value to the national economy. These losses are about 85% of the losses quoted in the fire loss estimates published by the British Insurance Association (BIA). The difference between the national economy losses and the BIA losses are accounted for by three factors:

- some of the BIA losses are estimated at replacement value rather than at the, lower, indemnity value.

- some of the BIA losses are not losses to the national economy.

- it is believed that there is a small degree of over-estimation in the losses published by the BIA.

It is possible that the losses in a sprinklered fire may be higher than in a non-sprinklered fire of the same size due to the additional water damage. There are certainly a number of individual, and spectacular, cases where this has occurred. The instances of serious water damage have generally occurred in buildings which were not occupied at the time of the fire and the sprinklers operated for many hours before the fire was noticed and the sprinklers switched off.

However there is insufficient usable data available to provide a separate estimate of unit loss for sprinklered fires and it is therefore assumed that the estimated unit loss figure applies to both sprinklered and non-sprinklered fires.

4.2 Consequential Losses

Direct losses occur at the time of the fire as the physical assets are destroyed or damaged. There may also be consequential losses resulting from the fire due to the loss of stocks or productive capacity and the disruption of business.

A study has been made of the consequential losses resulting from fire, considered both from the point of view of the firm and of the national economy.[10] Consequential losses may be considerably different when considered from the two different points of view. For example, if a firm loses stocks in a fire they may lose sales to their competitors and hence suffer a loss of profits. The firm's consequential loss will be equal to their loss of profits. However if the lost sales are made up by a British competitor (and this was found to occur in the majority of cases) then there is no net loss to the national economy. In terms of the national economy there is simply a transfer of profits from one firm to another. Generally, therefore, the consequential losses to the national economy are much less than the consequential losses experienced by individual firms.

The majority of fires involve no consequential losses to the national economy, and consequential losses occur only rarely. The study of consequential losses has shown, on average, that the consequential losses to the economy are equal to about 60% of the direct losses for fires in manufacturing industry and that, except in the case of electricity supply, there are no significant consequential losses in other fires.

The consequential losses to the firm are considerably higher and are estimated to be equal to, on average, about 110% of the direct losses in manufacturing industry and about 35% of the direct losses in other cases.

PART II

THE VALUE OF SPRINKLERS

5. THE ESTIMATION OF THE FIRE DAMAGE IF ONLY MINIMUM PROTECTION IS PROVIDED

5.1 Fires in sprinklered and non-sprinklered buildings

The requirement in this part of the analysis is to estimate the average amount of damage which might occur if a fire broke out in a building of a given occupancy, and that building had only the minimum level of fire protection.

This average amount of damage should be an overall average, reflecting the conditions and circumstances in all the buildings in that occupancy. (This concept is illustrated in Figure 1). It was therefore considered unsatisfactory to derive simply the required average from the fire records of those buildings which actually had only the minimum level of protection. It was suspected that the potential fire size in the protected buildings (ie the fire size which might have occurred if the buildings did not have additional protection) might be greater than the actual fire size in the unprotected buildings.

The information on the potential fire size in sprinklered buildings (ie the size of fire which might occur if the building were not sprinklered) comes from the survey of fires. In the survey the expected fire size which might result with each given level of fire protection was assessed for each fire. This information can be generalised and used to provide an estimate of the potential fire size for all the fires in sprinklered buildings in the K433 sample.

A number of attempts were made, using different models of fire growth, to derive general estimates of the potential fire size for fires in sprinklered buildings. However it was not possible to prove conclusively that the potential fire size in a sprinklered building is, on average, greater than the actual fire size in a non-sprinklered building of the same occupancy and the same floorspace. The failure to derive reliable estimates for the potential size of sprinklered fires is due to the scarcity of the data and the difficulty of developing a descriptive model of fire spread. In the absence of any reliable estimates of potential fire sizes in sprinklered buildings we are forced to use the assumption that the potential fire size in protected ildings is equal to the average fire size in unprotected buildings. However the experience of having examined the potential fire sizes in the sprinklered buildings does give more confidence that no serious bias is introduced by estimating the average fire size from the unrepresentative sample of unprotected buildings.

5.2 Average fire sizes in buildings without additional protection

The average fire size for buildings without additional protection is derived from the K433/SAF2 fire statistics, excluding those fires in buildings with sprinkler protection or automatic detectors.

If a fire occurs in a small building the spread of the fire may be limited by the outside walls of the building, whereas in a large building there is more room for the severe fires to spread. The average or expected size of a fire will therefore depend on the size of the building. In this analysis different mathematical models were used to estimate the average fire size but the most reliable model was found to be the simple model, average fire size = $d\ B^e$, where B is the total floorspace of the building and d and e are constants. The parameters d and e were estimated by a log-log regression on the K433/SAF2 data.

The estimated average fire sizes for the different occupancy groups are shown in Table 3. This table shows the sample size used in estimating the parameters, and also shows the predicted fire size in a 1500 m^2 building.

In 2 classes of buildings - hospitals and offices - the average fire size was found not to be a function of the building size. This seems intuitively reasonable. In hospitals almost all fires are detected and extinguished very promptly and therefore large hospitals do not have bigger fires than small hospitals. Office buildings are generally subdivided into a number of small compartments and the fire spread will be limited by the interior compartment walls rather than by the perimeter walls.

The estimates of fire sizes in a building of 1500 m^2 floorspace show that storage buildings have the largest fires and hospitals and offices the smallest fires. In industry the largest fires (for a fixed size of building) occur in "Other Manufacturing Industries" (mainly plastics and rubber), Timber and Furniture, and Paper, Printing and Publishing.

6. THE ESTIMATION OF THE FIRE DAMAGE IF SPRINKLERS ARE INSTALLED

6.1 The sub-division of the problem

The next step in the analysis is to estimate the average fire damage which would occur if a fire occurred in a building which was provided with a properly installed and well maintained sprinkler system. In order to simplify the calculation and allow more insight into the problem, the problem was sub-divided by considering a number of different types of fire. The types of fire considered are:

1. Fires which would not activate sprinklers.
2. Fires in which sprinklers fail to operate.
3. Fires in which sprinklers operate satisfactorily and control or extinguish the fire.
4. Fires in which sprinklers operate but are unable to control the fire.

Each type of fire is considered in turn and the separate results are then combined to provide an estimate of the expected fire damage in a sprinklered building.

The estimate of damage which is required is an estimate of the average damage which would occur if all buildings were sprinklered. The buildings in which sprinklers are currently installed as well as the buildings which are not sprinklered are therefore considered when deriving these estimates.

6.2 Fires which would not activate sprinklers

The fires which would not (and would not be expected to) activate sprinklers are those fires in which the sprinkler heads are not exposed to the heat of the fire (eg fires in ducts, fires in machinery, external fires, roof fires etc) or fires which are discovered promptly and extinguished before the sprinklers can operate. These fires are typically, small fires.

The results of the survey of the fires showed that there was no significant difference between the proportion of fires in sprinklered buildings which did not activate sprinklers and the proportion of fires in non-sprinklered buildings in which it was judged that sprinklers would not have operated. The survey results also showed that there was little difference between the average fire size when sprinklers did not operate in sprinklered buildings and the assumed size of the equivalent fires in non-sprinklered buildings. The necessary estimates for this group of fires in all buildings can therefore be derived from the statistics of fires in the sprinklered buildings.

The estimates of the performance of sprinkler systems were derived in a separate study and the full results of the study of sprinklered fires are reported elsewhere[11]. Essentially the study involved a detailed examination of the original K433 fire reports, and the information from the detailed study was then used to reinterpret the summary statistics obtained from a computer analysis of the K433 data. This study provided estimates of the proportion of fires in which sprinklers should not operate as well as the proportion of fires in which sprinklers failed to operate, operated satisfactorily or operated but were unable to contain the fire.

One modification must still be made to the statistics of fires in sprinklered buildings - a correction for the unreported sprinklered fires. It has been estimated that 10% of the fires in which sprinklers operate are not reported to the fire brigade. Therefore if the statistics of reported fires show that in a proportion p of these fires the sprinkler should not have operated, the corrected proportion p' for all the fires which are considered in this analysis is $p' = p/(1.1-.1p)$. The estimated proportions are shown in Table 4.

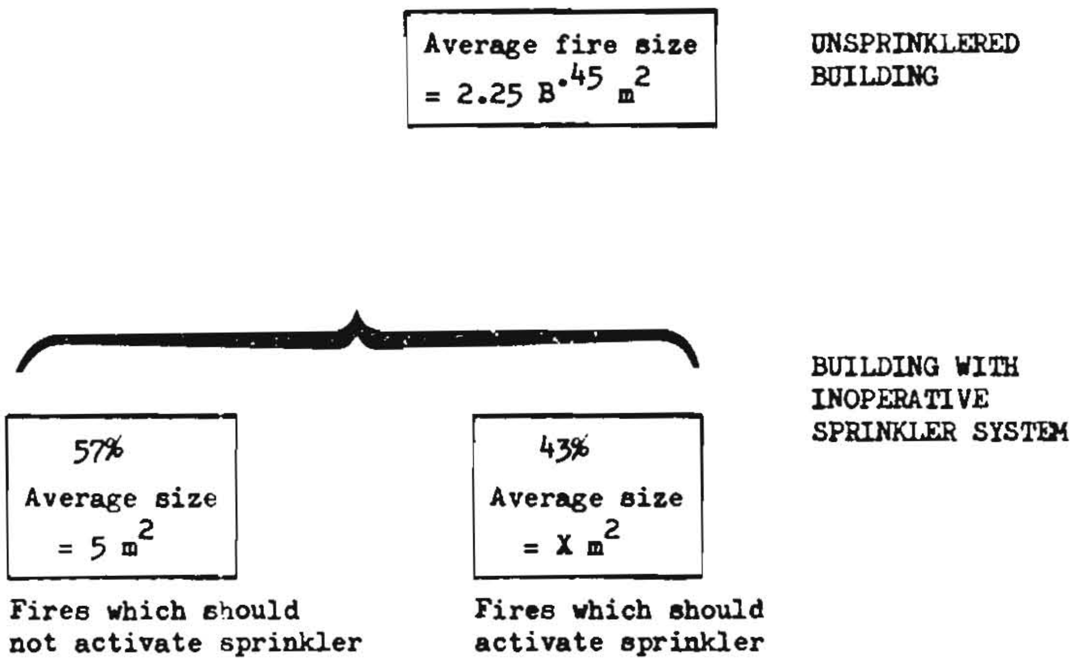
The average size of the reported fires which do not activate sprinklers was derived from the K433 and SAF2 fire reports for fires in sprinklered buildings. The estimated average sizes are shown in Table 4. The average size of these fires is of the order of a few square metres and the majority of these fires are confined to the item of origin.

6.3 <u>Fires in which sprinklers fail to operate</u>

There are a number of fires in which there is sufficient heat bearing on the sprinkler heads to operate the sprinkler but the sprinklers do not operate either because the sprinkler system has been shut off or because there is some mechanical defect (for example, a rusted valve). Most of these failures are caused by the system being shut off at the time of the fire. The system may be shut off for repairs or maintenance or for other, unexplained, reasons.

The probability of a sprinkler system failing to operate has been estimated, although it is not possible to derive an exact figure for the failure rate because of the difficulty of dealing with the cases in which sprinklers fail to operate but no reasons are given in the brigade fire report. It has been estimated that the failure rate, expressed as a proportion of those cases in which the sprinkler should operate, is between 2.1% and 3.1%, and in this analysis an intermediate figure of 2.5% has been used. If the figure is then corrected for the unreported sprinklered fires, the estimated failure rate is 2.5 x .9 = 2.2%.

If a sprinkler system is shut off before the fire or unable to operate due to a mechanical defect, the situation is equivalent to that in which no sprinkler system is installed. The average fire size in a building with an inoperative sprinkler system is therefore the same as the average fire size in a fire in an unsprinklered building. However, in this part of the calculation we are considering only those fires which should have operated sprinklers, and an allowance must be made for the small fires which would not operate sprinklers. The calculation of the required average fire size is illustrated below. The numbers used in this example are for all industrial buildings.



The required estimate of the fire size is shown as X in the figure above. As the 2 overall average fire sizes are equal, the quantity X can be calculated from the equation:

$$(.57 \times 5) + (.43 \times X) = 2.25\ B^{.45}$$

$$\text{Hence } X = 5.23B^{.45} - 6.63$$

The estimated proportions and average fire sizes for the different occupancies are shown in Table 4. For convenience the proportion of failures is expressed as a failure rate times the proportion of fires in which sprinklers should have operated.

6.4 Fire in which sprinklers fail to control the fire

There will be some fires which will activate the sprinkler system and will still grow very large despite the operation of the sprinklers. These fires may occur in conditions where a rapid fire starts in an area with a very high fire loading (explosions are the extreme cases of rapidly growing fires) or the fire may start in an inaccessible place such as a roof and cause serious damage before the sprinklers are activated.

It is impossible to draw a precise line between large fires which are controlled by the sprinkler system and large fires which can be regarded as "out of control". There is a continuum of fire sizes and any demarcation must be arbitrary and subjective. However in this study it is necessary to consider "out of control" fires as a separate group because these fires spread to most or much of the building and the average fire size will depend on the building size. In the case of fires which are contained by the sprinklers the fire will be localised and the amount of fire damage will be independent of the building size.

In the study we have considered an "out of control" fire to be a fire which has grown very large even though sprinklers have been activated. The estimation of the probability of these fires occurring is described in the report of sprinkler performance.[11] This probability depends on the occupancy and is, as would be expected, highest in the high risk industries such as chemicals, plastics and rubbers and is higher in storage buildings than in industrial buildings. In the fires which were judged as being "out of control" the average size was assumed to be about one third of the total building size. The estimates of the probabilities of "out of control" fires and average fire sizes in such cases are shown in Table 4. The probabilities have been corrected to take account of the unreported sprinklered fires.

The probabilities of "out of control" fires are derived from a study of the performance of sprinklers in buildings which are currently sprinklered. As sprinklers tend to be installed in more hazardous situations this may provide an overestimate of the probability of an "out of control" fire if <u>all</u> buildings were sprinklered. The results of the survey of fires did suggest that the probability of an "out of control" fire is lower in the unsprinklered buildings but the sample sizes were too small to provide reliable estimates. Therefore, in line with our policy of underestimating the value of sprinklers when in doubt, the estimates derived from the sprinklered buildings have been used in the analysis.

As previously mentioned, there is a continuum of fire sizes in sprinklered buildings. If the distribution of the number of heads opening in all sprinklered fires is considered[12] it can be seen that the 2½% of sprinklered fires which we have regarded as being "out of control" correspond approximately to the fires which have activated more than 35 sprinkler heads.

6.5 Fires in which sprinklers operate satisfactorily

After the fires in which sprinklers do not operate or fail to operate and the fires in which sprinklers operate but do not control the fire have been taken into account, the remaining fires are, by our definition, the fires in which the sprinkler system operated satisfactorily. The proportion of these fires was therefore found by difference. These proportions are shown in Table 4.

Information on the average amount of fire damage when the sprinkler system operates satisfactorily is available from the K433/SAF2 fire reports for sprinklered fires, and from the fire survey for fires in both sprinklered and (hypothetically) non-sprinklered buildings. The results of the fire survey showed that the average size of these fires in sprinklered buildings was no larger than the hypothesised size of these fires in sprinklered buildings. The average fire size in the survey fires was slightly smaller than in the fires reported on the K433/SAF2 reports. The average fire size derived from the K433/SAF2 sample has been used in the calculation, as these reports provide the largest and most representative sample. The estimates of the fire sizes are shown in Table 4.

6.6 The average damage in all fires

The 4 groups of fires can now be combined and the average fire size calculated from the data in Table 4 for sprinklered fires in any class of buildings. For example, the expected fire size in an industrial building of 1500 m^2 floorspace if the building was fitted with sprinklers would be:

$$(.57 + 5) + (.022 \times .43 \times (5.23 \times 1500^{.45} - 6.63)) + (.956 \times .43 \times 18) +$$
$$(.022 \times .43 \times \frac{1500}{3}) = 16.2 \text{ m}^2$$

7. THE COST OF A SPRINKLER SYSTEM

Estimates of the cost of sprinkler systems were obtained with the help of two of the major companies manufacturing and installing sprinklers. Estimates were provided of the cost of supplying and fitting extra low hazard, ordinary hazard and extra high hazard sprinkler systems into 3 simple buildings of different sizes. The relationship between the quoted costs and building size is linear and can be expressed in the form:

Extra Low Hazard: Cost (£) = 500 + 0.77 x size of building (m^2)
Ordinary Hazard: Cost (£) = 500 + 1.87 x size of building (m^2)
Extra High Hazard: Cost (£) = 500 + 2.53 x size of building (m^2)
(All costs are at 1977 prices).

The constant term represents the cost of the control valves and local alarm etc, and the variable portion the cost of the pipework and sprinkler heads. In a very large building more than one system will be required.

These costs do not include the cost of connecting the system to a suitable water supply. The cost of the water supply will include the cost of laying the pipes and making the connection to the mains. In some cases the mains supply will not satisfy the criteria laid down in the FOC rules and in these cases a water storage tank and pumping arrangements would be required.

We have estimated the costs of water supplies from figures made available to us of the costs of the water supplies for a number of new sprinkler installations. Our estimate of the cost of water supplies if no pumps are required is £(1500 + 1.3 x number of heads). This cost can be converted to a cost per square metre of building floor space using the FOC standards for sprinkler spacings.

For buildings which do not require pumps or additional water supplies, the estimated total cost of sprinklers and the associated water supplies is:

Extra low hazard: Cost (£) = 2000 + 0.83 x size of building (m^2)
Ordinary hazard: Cost (£) = 2000 + 1.98 x size of building (m^2)
Extra high hazard: Cost (£) = 2000 + 2.67 x size of building (m^2)

Pumps may be required for Extra High Hazard systems or in very tall buildings or other special cases and this increases the cost of water supplied considerably. Our estimate of the cost of water supplies in this case is £(13,500 + 3.7 x number of heads).

For an Extra High Hazard system which requires pumps and additional water supplies, the total cost will be:

$$\text{Cost } (\pounds) = 14000 + 2.94 \times \text{size of building } (m^2)$$

It should be noted that these costs are for the installation of sprinklers in buildings of a simple, open structure. If the building is divided into a number of small compartments or if the structure of the building is such that there are difficulties in placing the pipework then the costs will be higher than shown here.

The annual maintenance cost of sprinklers is relatively small, a figure of £50 having been quoted to us. In the literature a figure of 1% of the capital cost is quoted which is consistent with the above figure. Additional rates and water charges must be paid but these are small costs. Under the Plant and Machinery Rating Order 1960, 5 per cent of the capital cost of a sprinkler is liable for rates and a poundage of 70p in the pound has been assumed. The increase in water rates works out at approximately £0.00166/m^2 per annum.

The cost quoted here are the costs which must be paid by the owner or occupier of the building. However, when calculating the costs to the national economy it is the cost of the resources used which must be considered.

The cost to the national economy of providing and installing a sprinkler system may be calculated using complex arguments about the resources used in providing the sprinkler system and the alternative use which might be made of the resources if the sprinkler system had not been provided. In our calculations we have taken a simplified view of the economic problems. We have ignored the effects of such factors as imports and the existence of an export market for sprinklers and have assumed that the employees in the sprinkler industry would be productively employed elsewhere in the economy if they were not making and installing sprinklers. Under these simplifying assumptions the capital cost of a sprinkler in national economic terms is equal to the price actually paid by the purchasing firm. The maintenance cost is also a true economic cost, but the additional rates are only transfer payments and can be excluded.

8. A CHECK ON THE ESTIMATED PARAMETERS

Before using the estimated parameters to calculate the value of sprinklers it is important to check these estimates and to consider their accuracy.

The individual parameters have been checked wherever possible either by comparison with independent figures (for example, the parameters in the equations representing the probability of fire have been compared with published figures derived from European insurance company fire loss data), or by comparing the relative values of the parameters against intuition (for example, the estimated probability of an "out of control" fire is highest in the Chemical industry, which is intuitively reasonable). However it is not sufficient to check the individual parameters. It is also important to check that the individual estimates produce reasonable answers when combined in the final calculations. The estimates of the reduction in fire damage due to sprinklers have been checked in a variety of ways, and these checks are described here.

8.1 The estimated reduction in fire damage due to sprinklers

The expected fire damage if a fire occurs in a building with, and without, sprinklers can be calculated from the parameters given in Tables 3 and 4. The expected reduction in fire damage for buildings of a fixed size (1500 square metres, a typical size industrial building) has been calculated for different occupancies, and the results are shown in Table 5. The reduction in fire damage in the different occupancies varies between 60 per cent and 90 per cent. Among the industrial buildings the lowest percentage reduction is shown in Chemicals and Textiles. This may be accounted for by the fact that Chemicals have the highest probability of an "out of control" fire in which sprinklers would have, by definition, little or no effect. The relatively low figure for Textiles is accounted for by the number of fires which occur in large machines and in which sprinklers cannot reduce the fire size to less than that of the machine. It should be noted that estimates of the reduction in fire damage shown in Table 5 have deliberately been calculated on the conservative side.

These estimates of the reduction in fire damage can be compared with three other sets of figures - the survey results, the examination of large fires and insurance premium rebates.

1. <u>The survey results</u> In the survey the damage with and without sprinkler protection was observed (or assessed hypothetically) for every fire in either sprinklered or non-sprinklered premises. The estimated reduction in fire damage in the survey fires is as follows (after correction for the over-representation of Textiles and Metal Manafacturing):

Industrial buildings - sprinklered	$58m^2 \rightarrow 17m^2$,	71% reduction
Industrial buildings - non-sprinklered	$87m^2 \rightarrow 7m^2$,	93% reduction

(The difference in the percentage reduction between sprinklered and non-sprinklered buildings is not statistically significant).

Storage	$273m^2 \rightarrow 7m^2$	97% reduction
Shops	$24m^2 \rightarrow 4m^2$	85% reduction

These figures are in general agreement with the estimated figures in Table 5. (It must be remembered that the survey figures are the average figures for buildings of all sizes and some of the estimates are based on fairly small samples. The figures in Table 5 apply to 1500 square metre buildings, and have been derived directly or indirectly from much larger samples.)

2. <u>The examination of large fires</u> The fire losses are dominated by the large fires and if the fire losses can be reduced in the large fires then this will result in a considerable reduction in the total losses. The large fires have therefore been considered separately. The reduction in fire damage which could be achieved by sprinklers was estimated in the retrospective survey of large fires. The estimated reductions in fire damage are:

Industrial — 80-90% reduction

(The range of values is due to uncertainty about the possible effect of sprinklers in some of the fires.)

Storage — 92% reduction

Shops — 95% reduction

Other buildings — 76% reduction

These figures are also in general agreement with estimated figures of Table 5.

3. <u>The premium reductions offered by insurance companies</u> Insurance companies keep separate records for the claims for fires in sprinklered and in non-sprinklered premises. The premium reductions offered by insurance companies for the installation of an approved sprinkler system should therefore reflect

their claims experience and will be a measure of the reduction in fire damage which can be achieved by sprinkler systems. The premium rates are not published but it is believed that the premium reductions range from 60 per cent to 90 per cent. These figures provide further support for our estimates of fire damage.

8.2 The validity of the other parameters

The estimates of the reduction in fire damage are supported by other figures with which they can be compared. The other important parameters in the final calculations are the probability of a fire, the fire losses incurred in a fire of a given area of damage and the cost of a sprinkler system. We could find no alternative figures with which to compare these other estimates, but on the other hand there is no particular reason to doubt their validity.

The sensitivity of the final results to the assumptions and to the estimated parameters is examined in section 9.3.

9. THE VALUE OF SPRINKLERS FROM THE NATIONAL ECONOMY POINT OF VIEW

9.1 The use of discounted cash flows

The cost of a sprinkler system is equal to the initial installation cost plus the annual maintenance cost in subsequent years. The benefit of sprinkler systems is the reduction in the likely fire loss which may occur sometime in the future. At the planning stage, when considering the benefits of installing a sprinkler system, the benefits can only be expressed in probabilistic terms. In each and every future year there is a probability of a fire and an expected reduction in fire loss.

When comparing the cost (which occurs mainly in the year of installation) and the benefits (which occur, in expectation, in each future year) the standard accounting technique of discounted cash flow is used. All the cash sums are added together but the cash sums for future years are discounted to take into account the time preference for money. A discount rate of 10% is used and a sum of money which is paid, or received, in t years time is discounted by a factor $1/1.1^t$. The life of a sprinkler system is assumed to be 20 years, and the cash flows are summed over this period.

If the cost of installing a sprinkler system is C and the maintenance cost in future years is 1 per cent of the initial cost, then the total discounted cost is:

$$C + C\left(.01 + \frac{.01}{1.1} + \frac{.01}{1.1^2} + \dots\dots\dots \frac{.01}{1.1^{19}}\right)$$

$$= \quad 1.094C$$

If the average fire loss (including consequential loss) in an unsprinklered building is L_A, the average fire loss (including consequential loss) in a sprinklered building is L_B, and the probability of fire per year is p, then the expected reduction in fire losses per year is $p(L_A - L_B)$. The total discounted cost of future reductions in fire loss is:

$$p(L_A - L_B)\left(1 + \frac{1}{1.1} + \frac{1}{1.1^2} + \dots\dots \frac{1}{1.1^{19}}\right)$$

$$= \quad 9.36\, p(L_A - L_B)$$

The net discounted value of the sprinkler system, referred to as the net present value (NPV) is:

$$NPV = 9.36p(L_A - L_B) - 1.094C$$

If the net present value is positive (ie if the discounted benefits are greater than the discounted costs) then the installation of a sprinkler system can be said to be cost-effective.

9.2 <u>The calculation of the value of sprinklers</u>

The estimates of fire losses with, and without sprinklers, can be obtained from the estimates of fire damage presented in Tables 3 and 4, the unit loss figures in Table 2, and the consequential loss factor given in section 4.2. The probability of a fire is shown in Table 1 and the costs of sprinkler systems are given in section 3. This provides all the information needed to estimate the net present value of sprinklers from the national economy point of view using the formulae given above.

The value of sprinklers was calculated for the different occupancies and for different building sizes and the results are summarized in Figures 3 and 4.

Figure 3 shows that in industrial buildings the benefits of sprinklers outweigh the costs in buildings larger than about 800 square metres. The buildings larger than 800 square metres are the middle and larger industrial buildings, and account for approximately 50 per cent of all industrial buildings in number and about 90 per cent of the total floor-space in manufacturing industry.

Figure 3 also shows that sprinklers are of value only in the largest shops (greater than about 2000 square metres) and are not of value (and it should be remembered here that only property protection is being considered) in hospitals, offices and schools.

Perhaps the most surprising result is that sprinklers do not appear to be of value in storage buildings. This result is due to the fact that although the fires are, on average, large in storage buildings and fire sizes can be reduced considerably by sprinklers, the probability of a fire is very low. Thus when the costs of providing sprinklers are compared to the relatively small probability of making a large saving in fire losses the costs are still greater than the expected benefits.

The calculation of the value of sprinklers in storage buildings is admittedly the weakest part of the analysis. This is because the conditions and the fire risk in storage buildings can vary so much, and there are insufficient data available to allow the different types of storage to be identified and analysed separately. Section 9.3 describes an attempt to assess the value of sprinklers in different types of storage.

Sprinklers appear to be of value in larger hotels (above about 1600 square metres), but these calculations may overestimate the value of sprinklers. On the cost side, the assumed sprinkler costs were estimated for buildings of open construction, and in hotels, buildings which are highly compartmented, the cost of installing the sprinkler pipework may be higher. On the benefit side, the figures shown in Table 4 may underestimate the amount of fire damage which would occur in hotels if they were sprinklered. The estimates relating to hotels in Table 4 were derived, because of the sparsity of relevant data, from data on sprinklered fires in a miscellaneous group of buildings. If the individual bedrooms in a hotel were not sprinklered, and they would probably not be in practice, the average amount of damage in fires in sprinklered hotels might be larger than the estimates shown in Table 4.

The calculations suggest that sprinklers are not of value in pubs and restaurants. The estimated cost of ordinary hazard sprinkler systems in these buildings is greater than the estimated reduction in fire damage.

The value of sprinklers in different sectors of industry is shown in Figure 4. The results for separate industries must be treated with more caution, as the general assumptions may be less valid in the case of these more specialised groups and the parameters have had to be estimated from smaller samples. In particular, the curious results for the Chemical Industry are due to the relatively high probability of a sprinkler system failing to control a fire and the large amount of damage which it is assumed may occur in a large building in these circumstances.

The industries in which sprinklers appear to have the greatest value are Other Manufacturing (which includes rubber and plastic products), Food, Timber and Electrical Engineering.

9.3 The sensitivity of the results

The results for the two most important groups, industrial buildings and storage buildings, have been examined in order to determine how sensitive the results are to the assumptions made and the parameters used.

For industrial buildings the main assumptions used in the calculations are listed in Table 6, together with alternative assumptions which might be used. For most items the main assumptions are deliberately on the conservative side (ie undervalued sprinklers), and the alternative assumptions provide a more favourable estimate of the value of sprinklers. The estimated fire losses in an industrial building of size 1500 square metres are shown below, firstly calculated using the main assumptions, then calculated using all the assumptions which minimise the value of sprinklers, and finally, using the set of assumptions which maximise the value of sprinklers.

	Estimated loss per fire without sprinklers	Estimated loss per fire with sprinklers	Reduction in loss per fire	
"Main" Assumptions	£13600	£3700	£9900	(73%)
"Minimum value" Assumptions	£13600	£4400	£9200	(68%)
"Maximum value" Assumptions	£14050	£2700	£11350	(81%)

These results show that the estimated fire losses are fairly insensitive to the changes in assumptions. The reduction in fire losses per fire may be £700 less or £1450 more than the "best conservative" estimate. When the probability of a fire is considered the discounted value of the reduction in future fire losses may be £500 less or £1100 more than the "best conservative" estimate of £7600.

However when the other side of the picture, the cost of a sprinkler system is considered, the results are extremely sensitive to the assumed cost of the sprinklers. For a 1500 square metre building it is estimated that the cost of an ordinary hazard sprinkler system is about £5000. However if additional water supplies and pumps are required the cost may be many thousands of pounds more and this would completely change the net value of the sprinkler system.

It is recognised that the estimation of the value of fire protection in storage buildings is the weakest part of this study. The contents of a warehouse may vary from low hazard goods to high racked storage of highly combustible products, and the case for fire protection is quite different in these two different circumstances. However the available fire statistics are not sufficiently detailed to allow the nature of the goods and their wrapping or packing materials and the form of storage to be identified. In the main analysis all storage buildings are considered as a single group. In order to understand the differences between the different types of storage the effect of subdividing the storage group into a low hazard group, a high hazard group and an intermediate group has been examined. The subdivision can only be arbitrary as no reliable data are available for these sub-groups. (The parameter values assumed (and these assumptions are really no more than guesses) for the storage sub-groups shown in Table 7.)

The assumed parameters in Table 7 reflect the following characteristics of different types of storage:

- the probability of a fire is assumed to be the same in all types of storage

- the average fire size in an unprotected building is much greater in the high risk storage than in the low risk storage

- the average size of a fire which is controlled or extinguished by sprinklers is slightly larger in high risk storage than in low risk storage

- the probability of a fire growing out of control in a sprinklered building is much greater in high risk storage than in low risk storage.

The calculated value of sprinklers in the different types of storage is summarized in Table 5. The only type of storage in which sprinklers are of economic benefit is the high risk storage. If no pumps and additional water supplies are required then sprinklers will show a benefit in all but the smallest buildings. However if pumps and additional water supplies are required this adds about £12000 to the cost and sprinklers can only be justified economically in the very largest buildings.

9.4 The existing provision of sprinklers

The survey of manufacturing industry[4] provides estimates of the provision of sprinklers in industrial buildings. The results of the survey show that 13 per cent of buildings have complete sprinkler systems and a further 4 per cent have partial sprinkler systems. Sprinklers tend to be installed in larger buildings and sprinklers cover a total of about 35 per cent of the floor-space in manufacturing industry.

The sectors of industry with the greatest sprinkler coverage are Other Manufacturing (which includes rubber and plastic products), Textiles (where very many of the sprinkler systems are partial rather than complete systems), Paper, Timber, Chemicals, Clothing and Electrical Engineering.

9.5 Summary of the results

These calculations suggest that, from the national economy point of view, the provision of sprinkler protection would be of considerable benefit in most industrial buildings, in the larger shops, and in high risk areas, high value storage buildings. If additional water supplies are required this will add a very substantial amount to the cost of providing sprinklers, and may change the economic value of the system. We do not have sufficient information to be able to estimate the benefits due to the greater effectiveness of a sprinkler system which has additional water supplies.

Far fewer industrial buildings actually have sprinkler protection compared to the number of buildings in which this protection would be of economic value.

10. THE VALUE OF SPRINKLERS FROM THE FIRM'S POINT OF VIEW

The main purpose of this study is to assess the value of fire protection to the national economy. However it is also of some interest to compare the points of view of the firm and of the national economy and to consider the existing incentives to firms to install fire protection. We have therefore examined the decision to install sprinklers as it might be seen by the owner or occupier of the building, although we have taken a highly simplified view of the problem.

10.1 The basis of the calculation

When the owner or occupier of a building considers installing sprinklers he will examine the financial implications, but his decision will also be influenced by his awareness of the dangers of a fire and his attitude towards this risk. The only aspect of this decision we can represent in our analysis is the strictly financial aspect of the problem. In fact, much of the fire prevention literature and fire prevention publicity also considers the value of sprinklers from this financial point of view. A detailed account of the calculation of the financial benefits of fire protection system is given in a paper by Schofield.[13]

We have based our calculations on the assumption that the firm is fully insured against the direct and consequential losses from fire. Under this assumption the decision to install fire protection can be considered as an investment decision. The firm will have to pay for the sprinkler system (although this cost is partly offset by tax benefits and grants), but the firm will benefit from a reduction in insurance premiums. The value of the sprinklers will be equal to the difference between the costs and the benefits. The future costs and benefits will need to be discounted to present values and we have assumed a discount rate of 15% and a time horizon of 10 years for the discounted cash flow calculations. These discounting values are different to those used for the national economy calculations, and are more in line with the values which might be used by a commercial company when making an investment decision.

The value of sprinklers to a firm is assessed here for a "typical" industrial building.

10.2 The cost of providing fire protection

The purchase and installation cost for an ordinary hazard sprinkler system is assumed to be £2,000 + 2 x Building size (see section 7). There will also be an annual maintenance cost, additional rates and water rates. These annual costs are assumed to be about 5 per cent of the initial cost. (The figure of 1 per cent used in section 9 is the cost to the national economy, and includes only the maintenance cost.)

The discounted costs of providing a sprinkler system will therefore be:

$$£(2{,}000 + 2 \times B)\left(1 + \frac{.05}{1.15} + \ldots\ldots\right) = £(2{,}000 + 2 \times B) \times 1.29$$

All this expenditure is tax deductable, and if basic rate of tax is 52 per cent, the net (discounted) cost after tax will be equal to £ 0.48 x (2000 + 2.B) x 1.29

10.3 The benefits of providing fire protection

It is assumed here that the benefits of providing fire protection are the reductions in the premiums paid for direct loss and consequential loss insurance. Insurance premium rates are not publicly available and we have therefore had to estimate what these rates might be. We have estimated the premium rates making the following assumptions:

1. The ratio of premiums/claims is about 2:1. (This assumption is based on figures published in the Monopolies Commission report on fire insurance. Under this assumption, our estimate of the premium payable for a typical industrial building will be about 50p/£100.)

2. The premium reduction for sprinklers is equal to the expected reduction in fire loss if sprinklers are installed (this assumes that the insurance companies' loss ratios are the same for sprinklered and non-sprinklered risks).

3. a. The total consequential loss premium is equal to the direct loss premium. (It was estimated in our study of consequential losses that, on average, the consequential losses to the firm are, approximately equal to the direct losses. We have therefore assumed that if the firm is fully insured for consequential losses

the consequential loss premium would be as much as the direct loss premium. In practice the basis of consequential loss insurance is very much more complex.)

4. a. The percentage reduction on the consequential loss premium if sprinklers are installed is the same as the reduction on the direct loss premium. (This assumes that the installation of sprinklers will reduce consequential losses as much as it reduces direct losses, and that insurance companies therefore offer the same percentage reduction on the consequential loss premiums.)

Under these assumptions the premium reduction will be equal to 2 x 2 x (expected reduction in direct losses). The expected reduction in direct losses is known, and hence the amount of premium reduction can be estimated.

Because of our uncertainty about the assumptions made in these calculations, we have repeated the calculations with an alternative set of assumptions. The alternative assumptions to 3 and 4 above, are:

3. b. The total consequential loss premium is equal to half the direct loss premium. (This may imply that the firm are not fully insured for consequential losses, but it may be more in line with the figures actually used by the firm in their assessment of the advantages of installing sprinklers.)

4. b. The percentage reduction on the consequential loss premium is equal to half the reduction on the direct loss premium. (This assumption is based on reasoning that the overhead costs of providing insurance may not decrease proportionately with the lower risk, and therefore in order to maintain an acceptable profit margin, the premium cannot be reduced proportionately with the lower risk.)

Using these alternative assumptions the premium reduction will be equal to (2 + 2 x 0.5) x (expected reduction in direct losses).

The value of the premium reduction after tax will be equal to 48 per cent of the actual premium reduction. The net (discounted) cost after tax will therefore be equal to:

$$0.48 \times 4 \times \quad L\left(1 + \frac{1}{1.15} + \ldots\right) = 11.08 \ L \qquad (a)$$

$$\text{or} \quad 0.48 \times 2.5 \times \quad L\left(1 + \frac{1}{1.15} + \ldots\right) = 6.9 \ L \qquad (b)$$

where L is the expected reduction in fire loss.

10.4 The estimated value of sprinklers to the firm

Using the estimated costs and benefits given above the calculated value to the firm of installing sprinklers in industrial buildings of various sizes, and the comparative value to the national economy, are as follows:

Building Size m^2 Square metres	Estimated value to the firm NPV. £ Assumption (a)	Estimated value to the firm NPV. £ Assumption (b)	Estimated value to the national economy NPV. £
500	-100	-800	-900
1000	1200	-150	700
1500	2600	500	2300
2500	5100	1600	5300

These results show that for the larger buildings (above about 600 square metres or 1100 square metres depending on the assumptions made in the calculations) there is a financial advantage to a firm in installing sprinklers. (It must be remembered that this is a generalisation. There will be some particular cases where sprinklers are not suitable or appropriate.) The assessment from the firm's point of view is, in broad terms, in line with the national economy point of view ie in those industrial buildings in which sprinklers are of national economic benefit, there are financial incentives to the firms to install this protection.

If the buildings are in a development area the firm will be eligible for a grant if sprinklers are installed, and this increases the financial incentive to the firm.

This assessment of the value of sprinklers to a firm shows that there are a very large number of buildings in manufacturing industry in which there are financial incentives to install sprinklers. And yet the survey of manufacturing industry has shown that relatively few buildings have sprinkler protection. This raises the question of why so many firms have not taken advantage of the incentives which are being offered to them.

PART III

THE VALUE OF DETECTORS

11. THE ESTIMATION OF FIRE DAMAGE IF ONLY THE MINIMUM PROTECTION IS PROVIDED

11.1 The Sub-division of the problem

The expected fire damage if only minimum protection is provided has already been estimated for the sprinkler calculations. However, the assessment of detectors is a different problem to that of assessing sprinklers and it is convenient to re-estimate the minimum protection case, looking at the problem from a different point of view.

Detectors reduce fire damage by giving warning of a fire and allowing people to intervene earlier. The effectiveness of detectors will therefore depend largely on where the nearest people are when a fire occurs and how quickly they can tackle the fire. In this part of the analysis three separate situations are identified and each is then considered separately. The three situations are:

1. People are in the room of origin of the fire, or in the close vicinity of the fire, when the fire occurs.

2. People are in the building, but not in the room of origin, when the fire occurs.

3. People are not in the building when the fire occurs. This group of fires includes fires in which employees may be in an adjacent building or where there is a frequent security patrol, through to the other extreme where a fire occurs in a building in an isolated and deserted area on a weekend night.

11.2 The average fire size in buildings without additional protection

The average fire size for each situation - people in room, people in building, and people not in building - has been estimated from the 1970-71 K433/SAF2 fire data. (The position of the nearest person is recorded on the SAF2 fire report). These results have been checked against the survey data where the location of the nearest people was recorded in more detail.

Some difficulties were encountered in deriving a mathematical model which could be used to predict the average fire size as a function of the building size for fires in the three subgroups. The problems arise because of the inter-relationship between the variables. It appears that a higher proportion of fires in small buildings occur when there are no people in the building than is the case for larger buildings. (Perhaps because there are more people about in large buildings, and there is more likely to be night shift). However, considering the degree of accuracy required in this study and the gross assumptions made in other parts of the analysis it was not considered worthwhile developing a highly sophisticated model for the average size of fire in relation to the position of the nearest people. The estimated average fire sizes shown in Table 8 are derived using a simplified statistical model. This table shows the relative fire sizes according to the location of nearest people, in buildings of different sizes.

The figures in Table 8 show, as would be expected, that the fires which occur when there are no people in the building are on average larger than those fires which occur when people are in the building. These results also show that there are more likely to be people in the room of origin when a fire occurs in an industrial building compared to other occupancies. This is intuitively correct.

12. THE ESTIMATION OF FIRE DAMAGE IF DETECTORS ARE INSTALLED

12.1 The basis of the assessment

Sprinklers are mechanical systems and their effect can be predicted using theoretical and experimental results and the results of the analysis of fire statistics. In contrast, detectors operate by warning people of the fire and their effectiveness depends on the reaction of people, and this is much more difficult to predict.

Among the factors which determine the effectiveness of detectors are: where the nearest people are when the alarm sounds; whether the people will respond to the alarm and how long they take to respond; the rate at which the fire is growing; and how capable the people are of controlling or extinguishing the fire if they decide to tackle the fire. Little of this information is available, or can be deduced, from the brigade fire reports and we have had to rely largely on information obtained in our own survey of fires in this part of the analysis.

The prediction of the effect of detectors is considered separately for fires which occur when people are in the room, in the building or not in the building when the fire occurs.

12.2 Fires which occur when people are in the room of origin

The assumption has been made here that detectors will have no effect on the final amount of fire damage for those fires which occur when people are in the room (or close vicinity) when the fire occurs.

There will be some special cases where detectors will provide some benefit, for example by summoning help when the sole occupant of the room is trapped by the fire or is attempting to fight the fire. But these special and rare cases have been ignored and it is assumed that the average fire size if detectors are installed will be equal to the fire size if no detectors had been provided. The expected damage in this case is therefore equal to the values shown in the first columns of Table 8.

In industrial buildings the majority of the fires which occur when people are in the room are associated with, or caused by, the process. The second most frequent cause of fires is welding, cutting or the use of blowlamps (these activities may be part of the normal process activity in the building).

The process fires include fires caused by sparks or static from machinery, overheating of machinery, ovens and furnaces, the ignition of dust or waste in the machine or in a duct, and electrical faults in machinery.

In storage, there were very few fires which occurred when people were in the room, and the K433/SAF2 sample is too small to generalise about the causes of these fires.

In shops the main causes of fires which occurred when people were in the room of origin were overheating chokes on fluorescent lights (typically very small fires) and fires caused by space heaters, smokers materials and electrical faults.

12.3 Fires which occur when people are in the building

The first assumption made about the effect of detectors in fires which occur when people are in the building, but not the room of origin, is that both local alarm detectors and direct line detectors will have the same effect on the likely fire damage. This assumption is based on the experience of our survey of fires. Although this assumption is not strictly true (direct line systems may result in a quicker brigade response) it is a reasonable assumption to make in relation to the degree of accuracy pertaining in this part of the analysis.

The effect of detectors in reducing fire damage could be estimated from the fire survey alone. However in this analysis we have attempted to generalise the survey results and to make use of the very much larger sample of data available from the K433 and SAF2 fire reports.

It may be argued that the method of estimating the effect of detectors from the K433/SAF2 data described here is so speculative that it adds little to the validity of the answers which could be obtained if the survey data were used alone. However, this general analysis has been included because it does provide some support for the survey data, but equally importantly, it provides a clearer understanding of the predicted effects of detectors.

The most important single factor which determines the effect of direct line detectors is the initial growth rate of the fire. If the fire has a slow smouldering development initially, detectors may enable the fire to be detected and extinguished before much damage is caused, whereas if the fire has a very rapid growth initially, detectors can have little effect on the amount of damage. The most helpful clue on the fire report to the initial growth rate of the fire is the source of ignition. In some cases the source of ignition indicates the likely initial growth rate, although in other cases the information is less easily interpreted. For example, the experience of the fire survey shows that the majority of fires caused by discarded smokers materials would, if detectors were installed, be detected early and could be extinguished before much damage had been caused. However in the case of malicious fires some of the fires will have a rapid development (for example, when petrol is spilled and set alight in an area containing highly combustible material) while other malicious fires will have a relatively slow initial growth (for example, when lighted papers are pushed through a broken window and this causes a fire in an area where the contents are relatively incombustible).

The general estimation of the effect of detectors is based on the source of ignition recorded on the K433/SAF2 fire report. The number of fires and the average size of fires due to each cause can be estimated from the K433/SAF2 data and the effect of detectors on each group of fires can be estimated based on the experience of the fire survey. The results of this analysis for the "people in building" fires are summarised in Table 9.

The effect of detectors as estimated from the K433/SAF2 data covers a range of values, reflecting the uncertainty and variability associated with some of the causes, and is generally less than the survey estimate, reflecting the fact that the general estimates are on the conservative side.

In general detectors are estimated to be very effective in reducing the fire damage in those fires which occur when people are in the building, but not the room of origin. This is because many of the fires, and particularly fires caused by smokers materials, space heaters and wire and cable faults, have a slow, smouldering growth initially. When people are present in the building and are warned of the fire while it is still small the fires can generally be extinguished before much damage is caused. The experience of the survey showed how successful first-aid fire fighting could be in extinguishing small fires or at least in limiting the spread of these fires.

12.4 Fires which occur when there are no people in the building

The effect of detectors in the case of fires which occur when there are no people in the building has been estimated in the way described in section 12.3, and the results are summarised in Table 10.

For most occupancy groups the effect of detectors is estimated to be less than in the "people in building" fires. This is because most of the deliberate fires (arson, "doubtful" fires and fires caused by children with matches) are started when buildings are unoccupied, and detectors are less effective in the case of these rapid growth fires. Nevertheless, there are still many slow growth fires in unoccupied buildings and it is estimated that direct line detectors could reduce damage considerably in these fires.

The effect of local alarm systems depends on the presence of neighbours or security patrols and local alarm systems are therefore less effective than direct line systems.

12.5 The effect of detectors in all fires

The information in Tables 8,9 and 10 can be combined to produce an estimate of the overall effect of detectors. For example, for industrial buildings it is estimated (see Table 8) that the average damage in an unprotected building would be:

$$(0.55 \times 1.5.B^{.45} + .18 \times 1.9.B^{.45} + .27 \times 3.9.B^{.45}) = 2.22.B^{.45}$$

Now if the damage in the "people in building" fires is reduced by 60% and the damage in "people not in building" fires is reduced by 55% then the estimated fire size in a protected building would be:

$$(0.55 \times 1.5.B^{.45} + .18 \times .40 \times 1.9.B^{.45} + .27 \times .45 \times 3.9.B^{.45}) = 1.44\ B^{.45}$$

which is equivalent to a reduction of 35 per cent.

The estimated reduction in fire damage in all fires is shown in Table 11. Also shown in Table 11 is the estimated reduction in fire damage due to detectors in the survey fires. The survey results show a greater reduction than is obtained using the more conservative, general analysis. The estimated reduction in damage due to detectors is greater in shops and storage and least in industrial buildings.

The probability of a failure of the detector system has not been taken into account in these calculations. A study of fire calls to premises in which detectors are installed has been undertaken by the Fire Research Station.

During the survey period there were 777 fires in premises in which detectors were installed, and the system failed to give an alarm in 43 cases because it was disconnected or because of a failure or defect in the system. This is equivalent to a failure rate of 43/777 = .055.

If a 5 per cent failure rate is assumed in these calculations it would make a difference of 2-3 per cent in our estimates of the reduction in fire damage. Considering the accuracy of these calculations it was not considered worthwhile making this small correction.

13. THE COST OF A DETECTOR SYSTEM

The cost of providing and installing a detector system will depend on the type of detector installed, the number of heads required and the sophistication of the control system. The cost will also depend on the structure and geometry of the building as this will influence the amount of wiring required and the size of the area which can be covered by a detector.

Our information on the costs of detectors was provided by one of the major firms in the Fire Protection industry who provided estimates of the costs of the detector heads and the associated wiring for heat and smoke detectors. Although the cost of smoke detectors is greater than the cost of heat detectors, this is compensated for by the fact that smoke detectors will cover a larger area. When the costs are calculated in terms of the cost per square metre of building floor-space covered, both heat and smoke detectors have similar costs of about £1.1/m^2. Control equipment and an annunciator will also be required and this may cost about £1500. If the system is connected to a central alarm station there will be connection charges, and a figure of £250 has been assumed for these connection charges.

The initial costs of detector systems are thus:

Local alarm system	£1500 + 1.1 x Building size (m^2)
Direct line system	£1750 + 1.1 x Building size (m^2)

In future years there will be a maintenance cost for the detectors and a rental charge for the GPO line and the connection to the central alarm station. If the detectors are maintained and serviced by an outside contractor there will be a fixed charge plus an additional charge related to the number of heads to be checked. The maintenance cost is estimated to be £50 + £1.50/head or approximately £50 x 0.025 x Building size (m^2). For a system connected to a central alarm station the annual rental charges are assumed to be £200.

14. A CHECK ON THE ESTIMATED PARAMETERS

Before proceeding with the economic assessment of detectors a check was made on the estimated reduction in damage which could be achieved by detector systems. (Shown in Table 11.)

1. <u>The survey results</u> The generalised estimate of the effect of detectors is based largely on the experience of the fire survey, and the survey results do not therefore provide an independent check on the general estimates. However, as has already been stated, the estimated reduction in the survey fires is greater than the results produced in the general analysis and the general results may therefore be regarded as a conservative estimate of the effect of detectors.

2. <u>The survey of large fires</u> The retrospective survey of large fires produced the following estimates of the effect of detectors:

Occupancy	Number of fires	Reduction due to direct line systems	Reduction due to local alarm systems
Industry	37	-(48% to 58%)	-(27% to 46%)
Storage	21	-(74% to 87%)	- 69%
Shops	6	-(45% to 55%)	- 33%

The range of estimated values reflects the uncertainty about the possible effect of detectors in some of the fires.

For the two larger samples, industry and storage, these results agree closely with the results of the main survey.

3. <u>The fire damage in premises protected by detectors</u> Detectors are generally installed in larger buildings and are more likely to be installed in some sectors of industry than in others. The fire damage occuring in protected buildings can therefore only be assessed if compared with the fire damage in unprotected buildings of the same size and the same industries.

A check has been made on the fire damage recorded in the K433/SAF2 fire reports for buildings with detectors and for unprotected buildings.

The results of this comparison are as follows:

Occupancy	Average fire damage in buildings in which detectors are installed	Average fire damage in equivalent sample of unprotected buildings	Estimated reduction in fire damage
Industry (400 fires)	131 m^2	4 m^2	- 97%
Storage (18 fires)	344 m^2	119 m^2	- 65%
Shops (50 fires)	79 m^2	16 m^2	- 80%
Offices (50 fires)	15 m^2	1 m^2	- 93%

Because of difficulties of interpretation and problems of the consistency of the data, this comparison is not sufficiently reliable to be used on its own as evidence of the effectiveness of detectors. However it does provide further support for the estimates of the effectiveness of detectors.

4. Cerberus Fire Alarm Systems The only statistical evidence on the effect of detectors we have been able to find is the information published by Cerberus Limited - a Swiss manufacturer of fire alarm systems. Their figures show that in the period 1960-67 average fire losses were as follows:

	No of fires	Average fire loss in Swiss Francs
Fires in premises with Cerberus Systems	749	3827
Fires in other industrial, manufacturing, commercial, transport and administrative buildings	21226	11636

This is not a strict like-with-like comparison but it provides a further indication of the considerable reduction in fire losses which can be achieved by detectors.

5. Other European experience There is a hazard rating system known as the Gretener System which is widely used in Switzerland in determining insurance premium rates and in determining fire protection requirements. Numerical factors are used in the fire hazard equation representing the effect of different fire protection measures in reducing the fire hazard. The addition of an automatic fire alarm system with a direct line alarm reduces the calculated fire hazard by a factor of 0.57 (ie a reduction of 43 per cent). (The comparable figure for the addition of a sprinkler system implies a reduction of between 40 per cent and 70 per cent.)

The basis of the fire hazard calculation is not known, but whether it is based on fire statistics or subjective judgement or both, the factors in the fire hazard equation must reflect in a quantitative way the belief of the users of this scheme in the effectiveness of detectors.

Conclusion

There is no totally independent and reliable estimate of the effectiveness of detectors which can be used to validate the results of our analysis. However all the information which is available supports the main results presented in Table 11, and also suggests that the generalised estimates of the reduction in damage may be on the conservative side.

15. THE VALUE OF DETECTORS FROM THE NATIONAL ECONOMY POINT OF VIEW

15.1 The calculation of the value

The equation used in calculating the economic value of detectors is:-

NPV = Total discounted costs - Total discounted benefits

The initial and future annual costs of providing detectors are given in Section 13. The total discounted costs, discounting at 10 per cent over 20 years, will be equal to the initial cost plus 9.36 x future annual cost.

The total discounted benefits of the reduction in fire losses will be equal to $9.36p \times (L_A - L_B)$, where p is the probability of a fire (shown in Table 1), L_A is the average loss in an unprotected building (derived from Tables 2 and 3 and including consequential losses as described in section 4) and L_B is the average loss in a building provided with detectors (derived from the proportionate reduction in fire loss shown in Table 11).

The value of detector systems has been calculated for buildings of different occupancies and different sizes and the results are summarised in Figure 6, for direct line systems, and Figure 7 for local alarm systems.

In Figures 6 and 7 a range of values is shown for industrial buildings. This range reflects the range of alternative estimates of the reduction in fire damage. Only a single estimate of the economic value of detectors is shown for other occupancies in order to simplify the graphs. The single lines shown for the other occupancies are the mid-points of the range of values.

Figure 6 shows that direct line detectors appear to be of economic value in industrial buildings larger than about 2000 square metres (22 per cent of the buildings in manufacturing industry exceed this size). Figure 7 however shows that local alarm detector systems appear to be of economic value in industrial buildings larger than about 1300 square metres.

A comparison of the results for industrial buildings shown in Figures 6 and 7, is somewhat surprising. These results suggest that in industrial buildings, detection systems with local alarms are of equal or greater economic value than systems with direct line alarms. This result reflects both the characteristics of industrial fires and the experience of the survey. It is estimated that 73 per cent of the fires in industrial buildings occur when people are in the room of origin or in the building, and that these fires account for 52 per cent of the total fire damage (see Table 8). Thus about half of the total fire damage occurs in circumstances in which direct line detectors will offer little or no advantage over local alarm detectors. In the remaining fires which occur when there are no people in the building (and which account for 48 per cent of the total fire loss), it was estimated in the survey that local alarm detectors would reduce damage by 63 per cent compared to the 73 per cent reduction which would be achieved if there were direct line alarms. The success of local alarm detectors is explained by the fact that in many of the fires there were neighbours or security patrols or other employees nearby and it was judged that these people would have responded to a local alarm and would have been capable of extinguishing or at least containing the slow growing fires which were detected in the early stages of development. The effectiveness of local alarm detectors depends very much on the type of people who might be in the vicinity of the building in which the fire occurred and the survey results might possibly contain a regional bias. (The survey took place in West Yorkshire, South Yorkshire and Greater Manchester.)

Although direct line systems would achieve a slightly greater reduction in fire damage in industrial buildings this additional benefit does not offset the higher cost of providing a direct line system.

The only other occupancy in which detectors appear to be of economic value is shops. In shops direct line detectors appear to be of greater economic value than local alarm systems. This result reflects the fact that about 70 per cent of the fire damage in shops occurs in the fires which start when people are not in the building, and in the fire survey it was judged that local alarms would only reduce fire damage in these fires by 30 per cent compared to a reduction of 80 per cent achieved by direct line alarms. The relatively low effectiveness of local alarm detectors is due to the lesser readiness of neighbours to respond, their lesser ability to deal with a fire, and the rapid growth rates of some of the fires in shops.

15.2 The existing provision of detectors

The results of the survey of manufacturing industry show that about 4 per cent of buildings are fitted with detector systems, and in terms of total coverage, about 13 per cent of the floorspace in manufacturing industry is protected by automatic fire detection systems.

The industries which have the highest degree of fire detection coverage are Chemicals and Electrical and Instrument Engineering.

The results of this study show that there are very many more buildings in which automatic fire detection would be of benefit, compared to the number of buildings in which detectors are currently installed. However, the existing provision of detectors cannot be considered in isolation from the provision of sprinkler protection. The choice of sprinkler or detector protection is discussed in section 18.3.

15.3 The reliability of detectors

A serious problem associated with present automatic fire detection systems is their reliability. A study of direct line detector alarms[14] has shown that the ratio of false and accidental alarms to genuine alarms is about 11 : 1.

If there was more widespread use of direct line detector systems, and if the reliability of these systems was not improved, this high false alarm rate could cause serious problems for the fire brigades.

16. THE VALUE OF DETECTORS FROM THE FIRM'S POINT OF VIEW

As in the case of sprinklers, the value to the firm of installing detectors is calculated by comparing the cost of installing detectors with the benefits of reduced insurance premiums.

On the cost side, the cost of installing and maintaining an automatic fire detection system is given in Section 13. After tax, assuming a tax rate of 52 per cent, the net cost to the firm will be 48 per cent of the sums paid out.

On the benefit side the firm would benefit from a reduction in insurance premiums and would also receive a capital grant if the buildings were in a development area. Insurance companies offer premium reductions of up to $12\frac{1}{2}$ per cent, for the installation of approved, direct line fire detection systems. Because of the way insurance premiums are calculated a premium discount of $12\frac{1}{2}$ per cent may be equivalent to a reduction of more than $12\frac{1}{2}$ per cent on the premium actually payable. In this calculation of the benefits to the firm it has been assumed that the premium payable is reduced by 20 per cent.

Assuming that the firm is fully insured for consequential losses; that the consequential loss premium is equal to the direct loss premium, that the insurance companies premium/loss ratio is 2:1; and that both the direct loss and consequential loss premiums are reduced by 20 per cent, then the annual premium reduction will be:

0.2 x 4 x Expected annual direct fire loss, in an unprotected building.

The expected annual fire loss can be calculated from the information in Tables 1, 2 and 3. After tax the benefit to the firm will be equal to 48 per cent of the gross saving. The annual premium savings can be discounted at, say, 15 per cent over 10 years.

The estimated values to the firm of installing direct line detectors in "typical" industrial buildings of varying sizes are as follows:

Building size m^2	Estimated value to the firm NPV £	Estimated* value to the national economy NPV £
500	- 1280	- 3000
1500	- 870	- 1300
2500	- 470	400
3500	- 85	2060

*In calculating the value to the national economy, a 45 per cent reduction in fire damage has been assumed.

These results suggest that only in the very largest industrial buildings is there a financial incentive to firms to install detectors, and that there are many industrial buildings in which there would be an economic benefit to the national economy if detectors were installed, but there is no financial incentive to the firm to do so.

If the buildings are in a development area a tax free grant of 20 per cent of the capital cost of the detector system is payable. If this additional benefit is included in the calculation, there is a net benefit to the firm in buildings larger than about 2000 square metres, bringing the value from the firm's point of view in line with the national economic view.

PART IV

THE EFFECT OF IMPROVED STRUCTURAL FIRE RESISTANCE

17. THE ESTIMATION OF THE EFFECT OF IMPROVED STRUCTURAL FIRE RESISTANCE

The effect of improving the internal structural fire resistance could only be estimated in the fire survey, where the detailed on the spot examination enabled an assessment to be made of the effect the building structure had, or may have had, on the development of the fire. For every fire examined in the survey an assessment was made of the fire damage which might have occurred if all the existing internal surfaces (walls, ceilings, doors, floors etc) had had 30 minutes fire resistance, if they did not already have this fire resistance.

It should be noted that the survey assessments assumed improvements in the fire resistance of the existing structure, and did not consider the effect of putting in additional fire partitioning or separation.

The fires in which the amount of fire damage might have been reduced are those fires which spread beyond the room of origin, although some of these spreading fires could not have been affected by improved fire resistance. For example, in some of the spreading fires, doors had been left open, or a severe fire had burned for a very long time, and the survey assessments took into account those circumstances in which improved fire resistance would have made no difference.

There were also a few fires identified in the survey in which it was judged that improved structural fire resistance would have resulted in an increase in the amount of fire damage, because the improved partitioning would have delayed the discovery of the fire.

Overall, it was estimated for the survey fires that the upgrading of the internal structural fire resistance would have reduced the amount of fire damage by 45 per cent in industrial buildings, 50 per cent in storage buildings and 55 per cent in shops.

No estimate was made of the cost of upgrading the internal fire resistance, although it was clear that in many cases the cost would be substantial.

PART V

DISCUSSION OF THE RESULTS

18. DISCUSSION OF THE RESULTS

18.1 The method of analysis

At the outset of the study it was planned to use elaborate statistical methods and detailed models of fire growth in the analysis in order to produce results which were as accurate and reliable as possible. In particular the evaluation of sprinklers was to be based on a comparison of two strictly like-with-like (although artificial) samples of fires. In the evaluation of detectors it was intended to use detailed models of fire growth, which differentiated between fires confined to the item of origin, spread to the room and spread beyond the room, and between fires of different growth rates.

These more sophisticated methods and models have been examined and have been tried in the analysis, but the final results have been derived using very much simpler methods. The method finally used to determine the effectiveness of sprinklers is equivalent to a comparison of the fire damage in sprinklered and non-sprinklered buildings, though with the differences in the size and occupancies of the two samples taken into account. The final estimates of the effectiveness of detectors are not very different from the sample averages derived directly from the fire survey.

However, even though the more sophisticated methods have not been used in producing the final answers, the experience of having tried these elaborate methods has led to the development of the simpler methods, and has given us more confidence in the reliability and robustness of the final estimates of the reduction in fire damage due to sprinklers and detectors.

18.2 The limitations of the results

Before summarising the results of this study, the limitations of the results should be reiterated, to avoid any misunderstandings or misuse of the results.

1. The value of the fire protection measures has been determined only in relation to property protection, and the protection of life has been excluded. In occupancies such as hospitals, hotels and perhaps pubs and restaurants fire protection measures may be installed principally to protect life.

2. This analysis is concerned mainly with the value of sprinklers compared with having no fire protection and, as a separate question, the value of detectors again compared with having no fire protection. The value of other fire protection equipment or arrangements has not been assessed. There may

be other fire protection arrangements which offer better value. Among the arrangements not considered here are mixed systems (part of the building protected by sprinklers and part by detectors); partial systems (protecting only those parts of the building which are most vulnerable, or most valuable, or the highest risks); and other forms of fire protection such as smoke venting, CO_2 flooding etc.

3. A broad view of the problem has deliberately been taken and the value of fire protection has only been determined for various occupancies, each considered as a single group. These results will be applicable to the typical or average buildings within the group, but there may be many individual buildings in which the circumstances are different from the "typical" and for which the general results do not hold. Nevertheless, we believe that although the results are not detailed enough to apply to all the individual buildings, this should not invalidate the overall picture or the general results.

18.3 The choice of sprinklers or detectors

The survey of manufacturing industry shows that about 23 per cent of buildings have sprinkler or detector protection, and that a total of about 48 per cent of the floorspace in manufacturing industry is protected.

The estimates of the value of sprinklers and detectors show that, from the national economy point of view, sprinklers are of greater economic value than detectors in industrial buildings of any given size. As sprinklers are of value in about 50 per cent of industrial buildings, the conclusion still holds that the number of buildings in industry which would benefit from the installation of fire protection is far greater than the number which actually have sprinklers or detectors installed.

The result shown in the study, that sprinklers are of greater value than detectors in industrial buildings, is a general result and may hide the fact that there may be many individual buildings in which the circumstances are such that detectors are better value or are more appropriate. The circumstances in which detectors may be of more value would be where there are staff constantly about, ready to respond quickly to a fire call, and able to deal with a small fire; where the fire is likely to be small and slow burning in its early stages; and where contents may be badly damaged by the water from a sprinkler system.

18.4 Summary of the results

The principal objective of this study was to derive an overall picture of the value of fire protection from the national economy point of view. This overall picture is presented in Figures 1-3, which show the economic value of sprinklers and detectors in buildings of different occupancies and different sizes.

The main findings of the study can be summarised as follows:

1. Sprinklers are very effective in reducing fire damage, and will reduce the average fire damage by 70-90 per cent, (the different figures apply to buildings of different occupancies and different sizes). When the cost of providing sprinklers is compared with the savings in fire losses, it appears that sprinklers are of value (to the national economy) in medium and large industrial buildings, in large shops and in high value, high risk storage buildings.

2. From the firm's point of view, the premium reductions offered by the insurance companies provide a strong financial incentive to install sprinklers. Broadly speaking, in those buildings in which sprinklers offer a national economic benefit, there is a financial incentive to install sprinklers. However, far fewer firms in manufacturing industry have actually taken advantage of these incentives than would benefit from doing so. This raises the question of why firms should not have taken advantage of these financial incentives.

3. It is estimated that automatic fire detection would reduce fire damage by about 50 per cent on average in industrial buildings, and even more in other occupancies. When these savings in fire losses are compared with the cost of providing detectors it appears that automatic fire detection is of value in the larger industrial buildings and the larger shops. However the present high false alarm rate could cause serious problems for the fire brigades.

4. The insurance companies offer relatively small discounts for detectors, and thus, in general, there is little financial incentive for firms to install detectors. The incentive is greater in development areas, where capital grants are payable. In development areas, there is some financial benefit for the installation of detectors in industrial buildings in which detectors offer a net economic benefit.

5. It is estimated that improved internal structural fire resistance could reduce fire losses by about 50 per cent. No estimate has been made of the cost of these structural improvements.

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TABLE 1 THE PROBABILITY OF A FIRE IN DIFFERENT OCCUPANCIES

OCCUPANCY (SIC ORDER)	PROBABILITY OF FIRE PER YEAR $a.B^c$		PROBABILITY OF FIRE IN 1500m² BUILDING
	a.	c.	
INDUSTRIAL BUILDINGS:			
Food, drink and tobacco (III)	0.0011	0.60	0.086
Chemicals and allied (V)	0.0069	0.46	0.21
* Mechanical engineering (VII)	0.00011	0.75	0.027
Electrical engineering (IX)	0.00061	0.59	0.046
Vehicles (XI)	0.00012	0.86	0.062
* Metal goods not elsewhere specified (XII)	0.00158	0.54	0.082
Textiles (XIII)	0.0075	0.35	0.097
Timber, furniture (XVII)	0.00037	0.77	0.10
Paper, printing and publishing (XVIII)	0.000069	0.91	0.054
Other manufacturing (XIX)	0.0084	0.41	0.17
All manufacturing industry (III-XIX)	0.0017	0.53	0.082
OTHER OCCUPANCIES:			
Storage	0.00067	0.5	0.026
Shops	0.000066	1.0	0.099
Offices	0.000059	0.9	0.043
Hotels etc	0.00008	1.0	0.12
Hospitals etc	0.0007	0.75	0.17
** Pubs, restaurants etc	(0.00007)	(1.0)	(0.1)
Schools	0.0002	0.75	0.048

*Note: Some of the fires which should be included in the Mechanical engineering sector may have been classified as "Metal goods n.e.s." This would result in an underestimate of the probability of fire for Mechanical engineering and an overestimate for Metal goods. If the two groups are combined the estimated probability of fire is 0.00086 $B^{.56}$.

**Values for Assembly are assumed. There was insufficient information available to estimate the probability of fire in this occupancy group.

TABLE 2 THE AVERAGE DIRECT LOSS PER UNIT AREA OF FIRE DAMAGE

OCCUPANCY (SIC ORDER)	UNIT LOSS (£/sq.m)
INDUSTRIAL BUILDINGS:	
All industry	140
Food, drink & tobacco (III)	270
Chemicals & allied (V)	300
Mechanical engineering (VII)	290
Electrical engineering (IX)	320
Vehicles (XI)	150
Metal goods not elsewhere specified (XII)	240
Textiles (XIII)	210
Timber, furniture (XVII)	130
Paper, printing & publishing (XVIII)	90
Other manufacturing (XIX)	120
OTHER OCCUPANCIES:	
Storage	120
Shops	160
Offices	150
Hotels etc	130
Hospitals etc	160
Pubs, restaurants etc	100
Schools	110

TABLE 3 THE ESTIMATED FIRE DAMAGE IF ONLY THE MINIMUM LEVEL OF PROTECTION IS PROVIDED

OCCUPANCY (SIC ORDER)	AVERAGE FIRE SIZE AS A FUNCTION OF BUILDING SIZE(m^2)	SAMPLE SIZE	AVERAGE FIRE SIZE IN A BUILDING OF 1500m^2 FLOORSPACE
INDUSTRIAL BUILDINGS:			
All industry	$2.25\ B^{.45}$	6496	60
Food, drink & tobacco (III)	$2.7\ B^{.45}$	313	73
Chemicals & allied (V)	$11.8\ B^{.12}$	516	28
Mechanical engineering (VII)	$0.17\ B^{.76}$	248	44
Electrical engineering (IX)	$18.5\ B^{.17}$	174	64
Vehicles (XI)	$0.80\ B^{.58}$	181	56
Metal goods not elsewhere specified (XII)	$6.4\ B^{.23}$	561	34
Textiles (XIII)	$2.6\ B^{.39}$	399	45
Timber, furniture (XVII)	$24.2\ B^{.21}$	393	112
Paper, printing & publishing (XVIII)	$6.7\ B^{.36}$	198	93
Other manufacturing (XIX)	$8.7\ B^{.38}$	228	140
OTHER OCCUPANCIES:			
Storage	$3.5\ B^{.52}$	1398	157
Shops	$0.95\ B^{.50}$	2662	37
Offices	15.0	622	15
Hotels etc	$5.4\ B^{.22}$	973	27
Hospitals	5.0	936	5
Pubs, restaurants etc	$7.6\ B^{.20}$	2908	33
Schools etc	$2.8\ B^{.37}$	906	42

TABLE 4 THE ESTIMATED AVERAGE AREA OF FIRE DAMAGE IF SPRINKLERS ARE INSTALLED

OCCUPANCY (SIC ORDER)	SPRINKLERS NOT ACTIVATED		SPRINKLERS FAILED		SPRINKLERS OPERATED SATISFACTORILY		SPRINKLERS "COULD NOT COPE"	
	Propn.	Av.damage(m^2)	Propn.	Av.damage(m^2)	Propn.	Av.damage(m^2)	Propn.	Av.damage(m^2)
INDUSTRIAL BUILDINGS:								
All industry	.57	5	.022x.43	$5.23 B^{.45} - 6.63$	.956x.43	18	.022x.43	B/3
Food, drink & tobacco (III)	.69	3	.022x.31	$8.78 B^{.45} - 6.7$	.968x.31	2	.010x.31	B/3
Chemicals & allied (V)	.60	2	.022x.40	$29.5 B^{.12} - 3.0$	.942x.40	9	.032x.40	B/3
Mechanical engineering (VII)	.42	1	.022x.58	$0.29 B^{.76} - 0.72$	.968x.58	1	.010x.58	B/3
Electrical engineering (IX)	.47	1	.022x.53	$34.9 B^{.17} - 0.89$	.968x.53	3.5	.01x.53	B/3
Vehicles (XI)	.87	1	.022x.13	$6.2 B^{.58} - 6.7$	.966x.13	9	.01x.13	B/3
Metal goods not elsewhere specified (XII)	.42	1	.022x.58	$11.0 B^{.23} - 0.72$	.968x.58	6	.01x.58	B/3
Textiles (XIII)	.53	7	.022x.47	$5.5 B^{.39} - 7.9$	.960x.47	25	.018x.47	B/3
Timber, furniture (XVII)	.40	2	.022x.60	$40.3 B^{.21} - 1.3$	.963x.60	14	.01x.60	B/3
Paper, printing & publishing (XVIII)	.40	1	.022x.60	$11.2 B^{.36} - 0.7$	.956x.60	15	.019x.60	B/3
Other manufacturing (XIX)	.70	4	.022x.30	$29.0 B^{.38} - 9.3$	.915x.30	30	.065x.30	B/3
OTHER OCCUPANCIES								
Storage	.24	2	.022x.76	$4.6 B^{.52} - 0.63$	.928x.76	16	.05x.76	B/3
Shops	.55	1	.022x.45	$2.11 B^{.50} - 1.2$	.958x.45	1	.02x.45	B/3
Offices				27.5				
Hotels etc				$10.6 B^{.22} - 1.9$				
Hospitals etc				7.9				
Pubs, restaurants etc	.49	2	.022x.51	$14.9 B^{.20} - 1.9$	.973x.51	2	.005x.51	B/5
Schools etc				$5.5 B^{.31} - 1.9$				

TABLE 5 THE ESTIMATED REDUCTION IN FIRE DAMAGE IF SPRINKLERS ARE INSTALLED

Occupancy	Average fire size in 1500 m^2 building. (m^2)		Reduction in damage due to sprinklers
	Without sprinklers	With sprinklers	
All industry	60	16	73%
Food, drink and tobacco	73	6	92%
Chemicals and allied	28	12	57%
Mech eng	44	5	88%
Elec eng	64	6	91%
Vehicles	56	4	93%
Metal goods	34	7	79%
Textiles	45	20	56%
Timber	112	14	87%
Paper	93	17	82%
Other mnfr	140	24	83%
OTHER OCCUPANCIES			
Storage	157	23	85%
Shops	37	6	84%
Offices	15	3	80%
Hotels etc	27	3	89%
Hospitals etc	5	3	40%
Pubs etc	33	3	91%
Schools	42	3	93%

TABLE 6 ALTERNATIVE ASSUMPTIONS WHICH MIGHT BE USED IN ESTIMATING THE VALUE OF SPRINKLERS IN INDUSTRIAL BUILDINGS

Item	Assumption used in the analysis	Alternative Assumption	Effect of alternative assumption on estimated value of sprinklers
1. Potential size of fires in buildings actually sprinklered.	Equal to the average size in non-sprinklered buildings	Fires in sprinklered buildings are, potentially, 20% larger than fires in non-sprinklered buildings	Better value
2. Sprinkler failure rate	2.2%	1.5%	Better value
3. Probability of sprinklers allowing fire to get "out of control"	2.2%	1.5%	Better value
4. Average size of "out of control" fire	B/3 m^2	B/5 m^2	Better value
5. Average size of fire when sprinklers operate satisfactorily	18 m^2	15 m^2	Better value
6. Fire losses in sprinklered fires	Equal to fire losses in non-sprinklered fires (= £140/m^2)	20% greater than in non-sprinklered fires (= £168/m^2)	Worse value
7. Cost of sprinkler system	Pumps not required in ordinary hazard system Cost = £2,000 + 2.B	Additional water supplies and pumps required	Worse value

TABLE 7 THE ASSUMED PARAMETER VALUES FOR THE CALCULATION OF THE VALUE OF SPRINKLERS IN DIFFERENT TYPES OF STORAGE

Item	Estimated value for all storage buildings	Assumed parameter values		
		Low hazard	Intermediate	High Hazard
Probability of a fire per year	$0.00067\ B^{.5}$	$0.00067\ B^{.5}$	$0.00067\ B^{.5}$	$0.00067\ B^{.5}$
Average fire size without sprinklers	$3.5\ B^{.52}$	$2.0\ B^{.52}$	$3.5\ B^{.52}$	$7.0\ B^{.52}$
Probability of sprinklers not activating	0.24	0.24	0.24	0.24
Probability of sprinkler failure	0.022	0.022	0.022	0.022
Probability of "out of control" fire	.05	0.02	0.05	0.07
Average fire size when sprinklers:				
do not operate	2	2	2	2
operate successfully	16	12	16	20
"cannot cope"	B/3	B/4	B/3	B/2
Direct loss per unit area of fire damage	120	115	115	180 (high piled storage)
Cost of sprinkler system		2000 + 2.B (ordinary hazard)	2000 + 2.B (ordinary hazard)	2000 + 2.67B (extra high hazard) 14000 + 2.94B (extra high hazard, with additional water supplies)

TABLE 8 THE ESTIMATED FIRE DAMAGE IF ONLY THE MINIMUM LEVEL OF FIRE PROTECTION IS PROVIDED - ANALYSED ACCORDING TO THE LOCATION OF THE NEAREST PERSON.

Occupancy	People in room		People in building		People not in building	
	Average fire size m^2	Proportion of fires	Average fire size m^2	Proportion of fires	Average fire size m^2	Proportion of fires
Industry	$1.5\ B^{.45}$	55%	$1.9\ B^{.45}$	18%	$3.9\ B^{.45}$	27%
Storage	$2.8\ B^{.52}$	20%	$2.8\ B^{.52}$	15%	$3.9\ B^{.52}$	65%
Shops	$0.7\ B^{.50}$	20%	$0.7\ B^{.50}$	25%	$1.2\ B^{.50}$	55%
Offices	10	20%	10	50%	28	30%
Hotels	$4.7\ B^{.22}$	30%	$3.6\ B^{.22}$	60%	$18.\ B^{.22}$	10%
Hospitals	5.0	45%	5.0	45%	6.0	10%
Pubs, restaurants etc	$3.0\ B^{.20}$	30%	$5.0\ B^{.20}$	30%	$13.0\ B^{.20}$	40%
Schools	$2.2\ B^{.37}$	20%	$2.5\ B^{.37}$	30%	$3.2\ B^{.37}$	50%

TABLE 9 THE ESTIMATED REDUCTION IN FIRE DAMAGE DUE TO DETECTORS - "PEOPLE IN BUILDING" FIRES

Occupancy	Causes of larger fires	Reduction in fire damage			
		With direct line alarm		With local alarm	
		Estimated from K433/SAF2	Estimated in survey	Estimated From K433/SAF2	Estimated in survey
Industry	Process fires Smokers materials Space heaters Wire and cable Welding Malicious	-(65%-85%)	-95%	-(65%-85%)	-95%
Storage	Smokers materials Space heaters Malicious Wire and cable Welding	-(70%-85%)	small sample	-(70%-85%)	small sample
Shops	Smokers materials Wire and cable Space heaters Appliances (including lighting)	-(90%-95%)	-93%	-(90%-95%)	-93%
Offices	Misc. appliances Wire and cable Space heaters	-(80%-95%)	small sample	-	small sample
Hotels	Wire and cable Cookers Space heaters Smokers materials	-(80%-90%)	small sample	-	small sample
Pubs and restaurants	Malicious fires Space heaters Smokers materials	-(65%-80%)	small sample	-	small sample
Schools	Cookers Malicious fires Smokers materials	-(70%-85%)	small sample	-	small sample

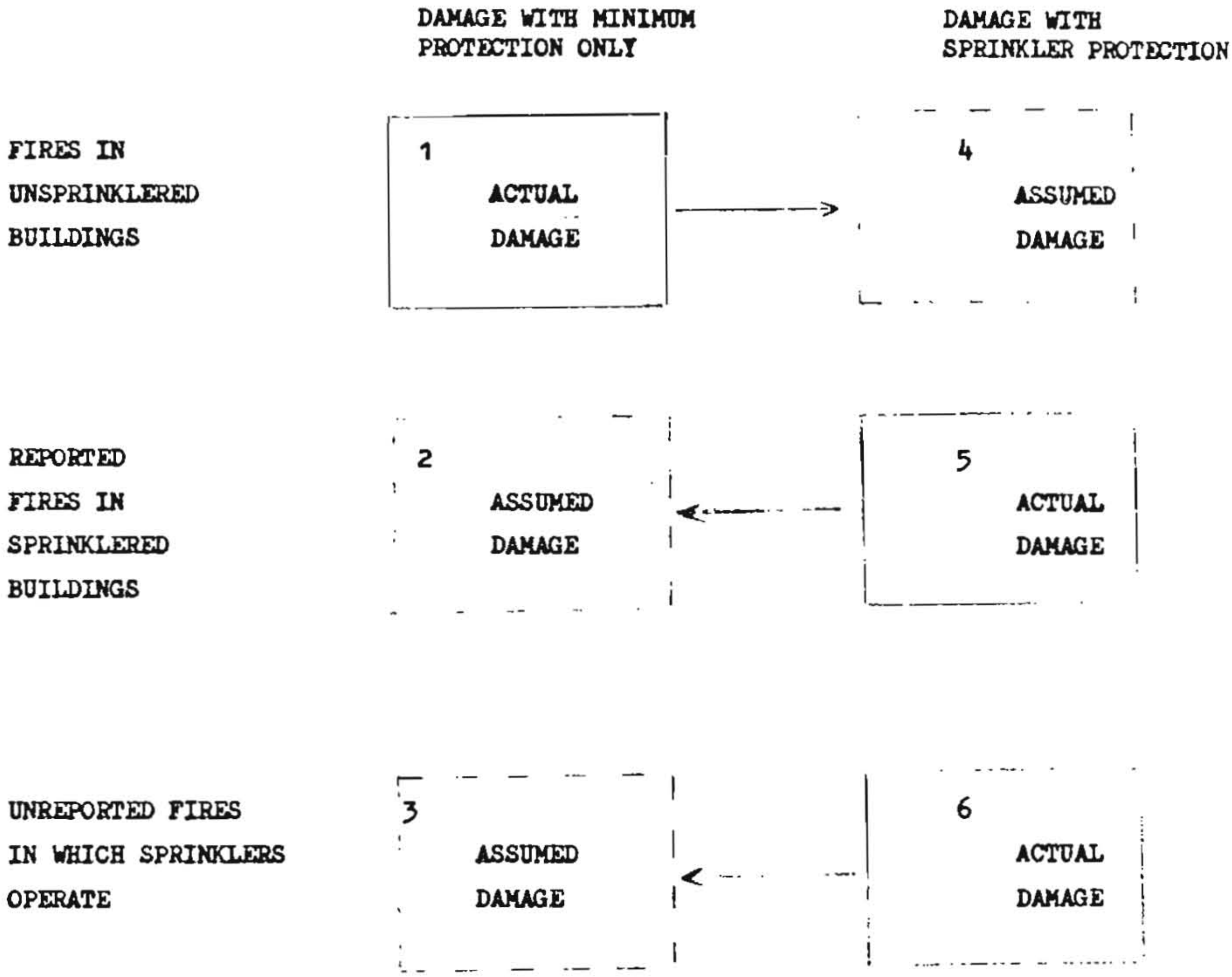
TABLE 10 THE ESTIMATED REDUCTION IN FIRE DAMAGE DUE TO DETECTORS - "PEOPLE NOT IN BUILDING" FIRES

Occupancy	Causes of larger fires	Reduction in fire damage			
		With direct line alarm		With local alarm	
		Estimated from K433/SAF2	Estimated in survey	Estimated from K433/SAF2	Estimated in survey
Industry	Malicious fires Process fires Space heaters Smokers materials Welding Wire and cable	-(65%-85%)	-73%	-(55%-75%)	-63%
Storage	Malicious fires Smokers materials Space heaters Wire and cable	-(70%-85%)	-83%	-(50%-60%)	-60%
Shops	Malicious fires Smokers materials Appliances (including lighting) Wire and cable Space heaters	-(70%-85%)	-80%	-(25%-30%)	-30%
Offices	Malicious fires Smokers materials Wire and cable	-(50%-70%)	small sample	not estimated	small sample
Hotels	Misc. appliances Malicious fires Space heaters	-(70%-90%)	small sample	not estimated	small sample
Pubs and restaurants	Malicious fires Smokers materials Wire and cable	-(70%-85%)	small sample	not estimated	small sample
Schools	Malicious fires Space heaters Smokers materials	-(60%-80%)	small sample	not estimated	small sample

TABLE 11 THE ESTIMATED REDUCTION IN FIRE DAMAGE DUE TO DETECTORS - ALL FIRES

Occupancy	Survey sample size	Reduction in fire damage			
		With direct line alarm		With local alarm	
		Estimated from K433/SAF2	Estimated in Survey	Estimated from K433/SAF2	Estimated in Survey
Industry	210	-(40%-55%)	-55%	-(35%-50%)	-50%
Storage	30	-(60%-70%)	-80%	-(45%-55%)	-60%
Shops	50	-(65%-75%)	-85%	-(35%-40%)	-40%
Offices	17	-(55%-70%)	-45%	not estimated	-40%
Hotels	12	-(55%-65%)	-85%	not estimated	-85%
Pubs, restaurants	36	-(60%-75%)	-55%	not estimated	-40%
Schools	26	-(55%-70%)	-90%	not estimated	-85%

FIGURE 1. THE ESTIMATION OF FIRE DAMAGE WITH AND WITHOUT SPRINKLER PROTECTION



Damage with minimum protection only = 1 + 2 + 3

Damage with sprinkler protection = 4 + 5 + 6

FIGURE 2 PROBABILITY OF A FIRE OCCURRING — PRODUCTION BUILDINGS, MANUFACTURING INDUSTRY

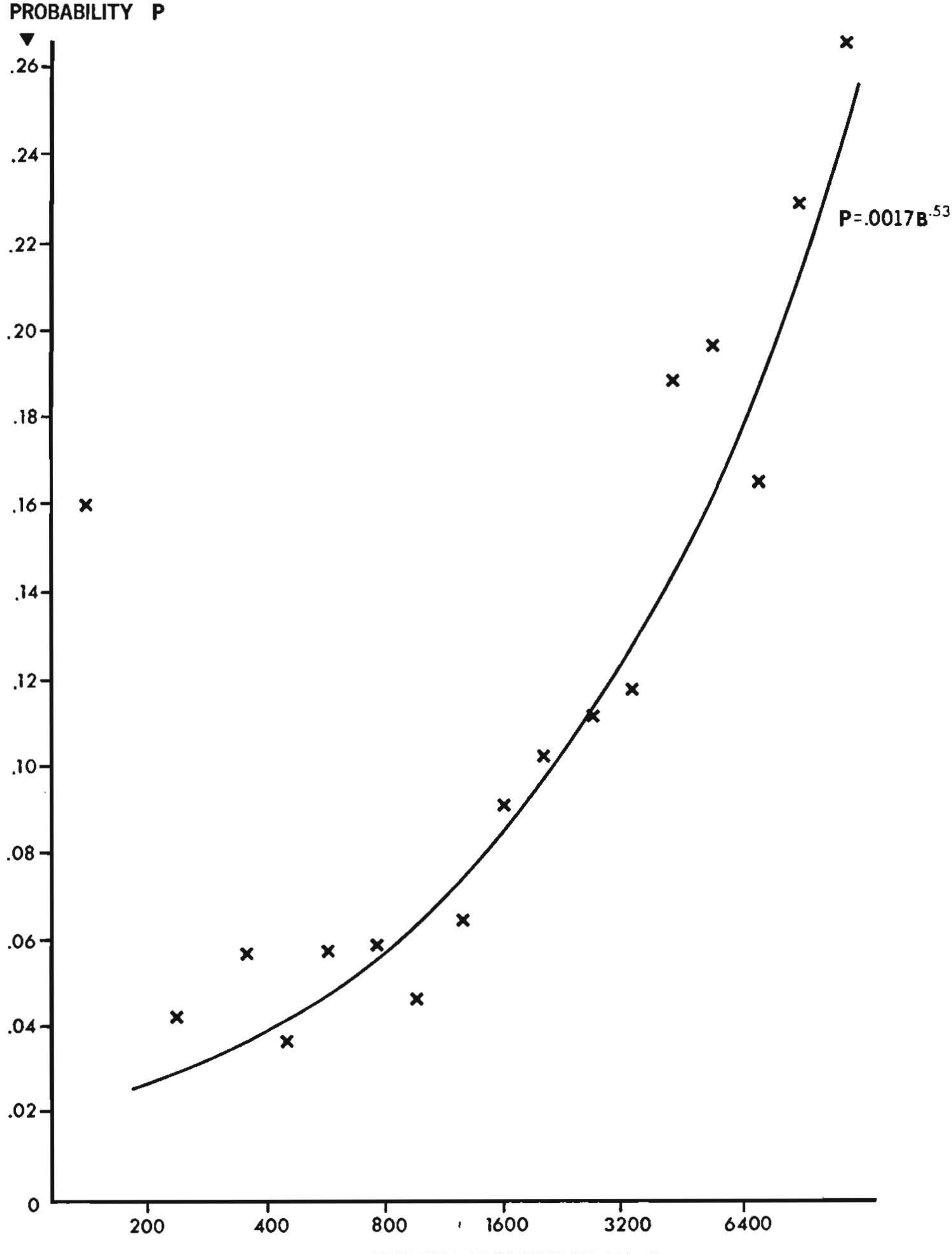


Figure 3 THE VALUE OF SPRINKLERS IN DIFFERENT OCCUPANCIES

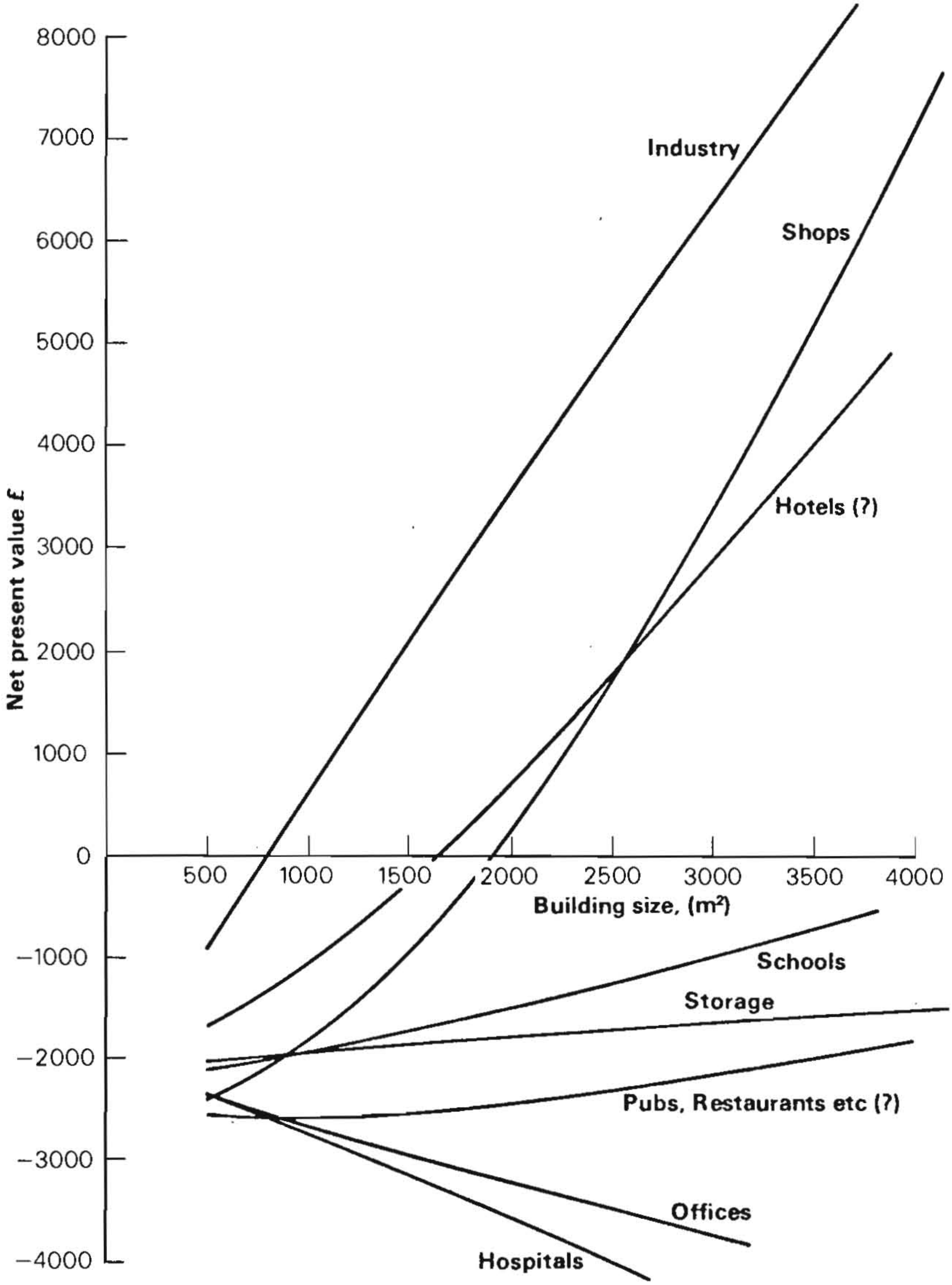


Figure 4 THE VALUE OF SPRINKLERS IN DIFFERENT SECTORS OF INDUSTRY

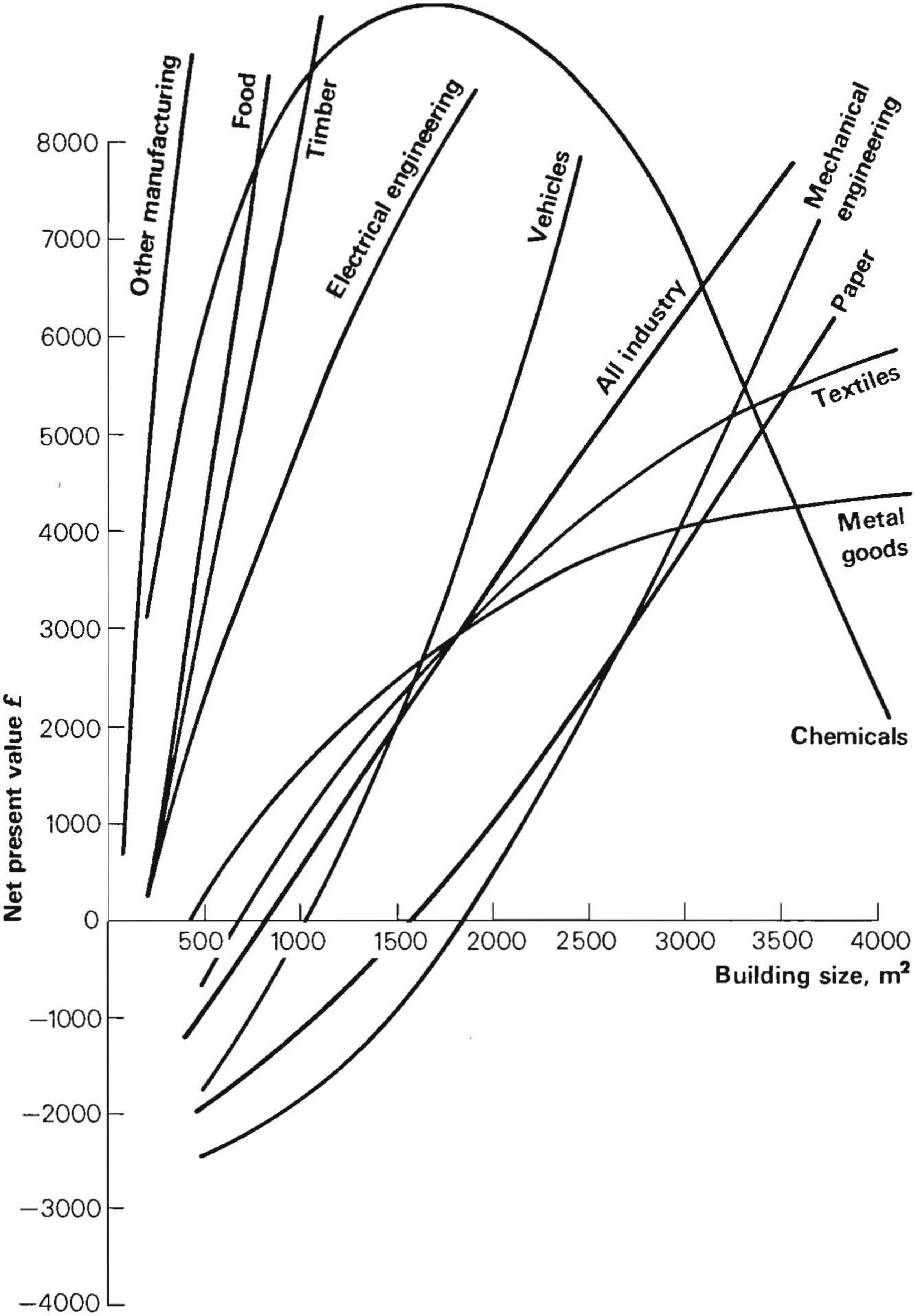


Figure 5 THE ESTIMATED VALUE OF SPRINKLERS IN DIFFERENT TYPES OF STORAGE

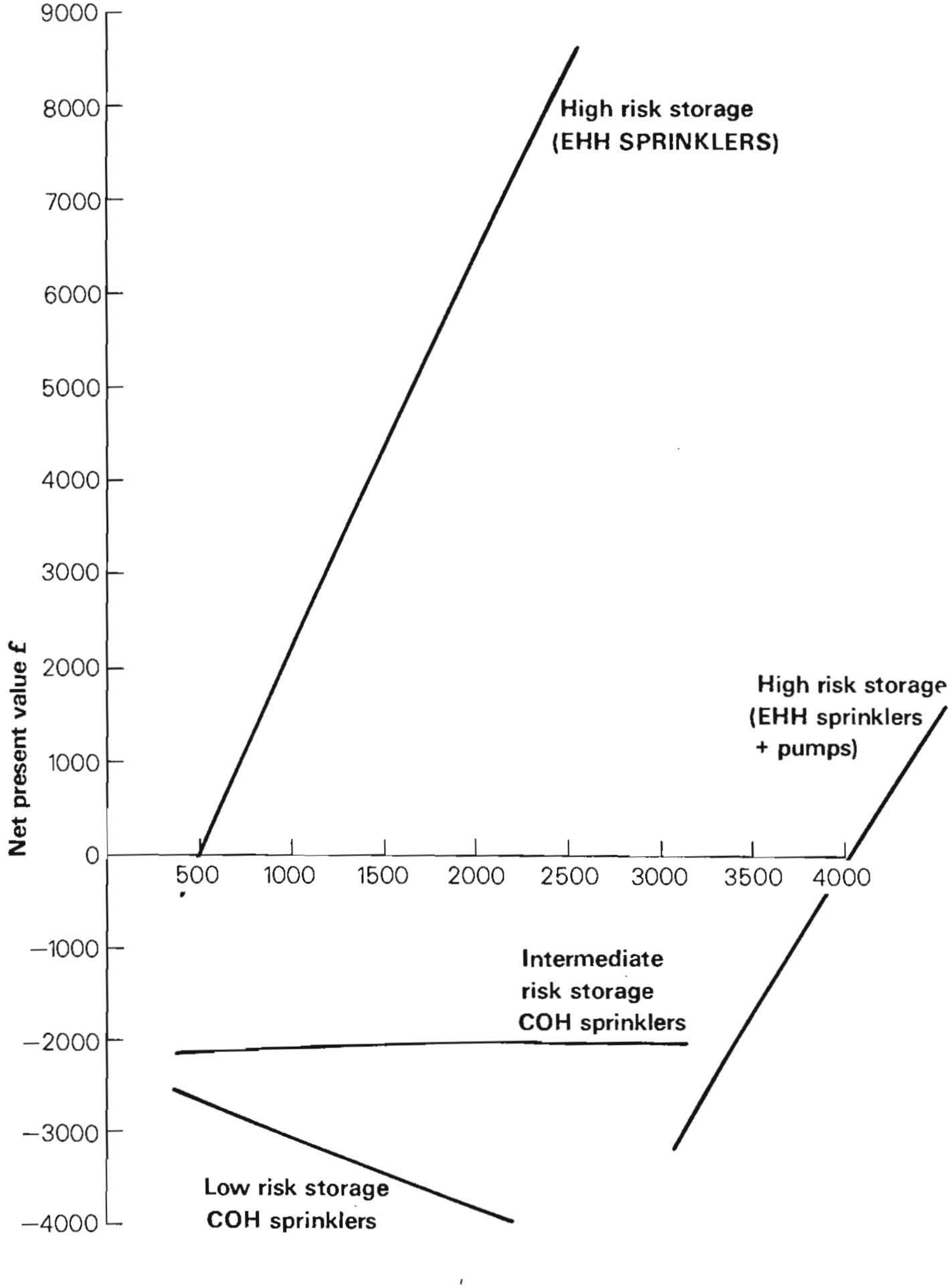


Figure 6 THE VALUE OF DIRECT LINE DETECTORS IN DIFFERENT OCCUPANCIES

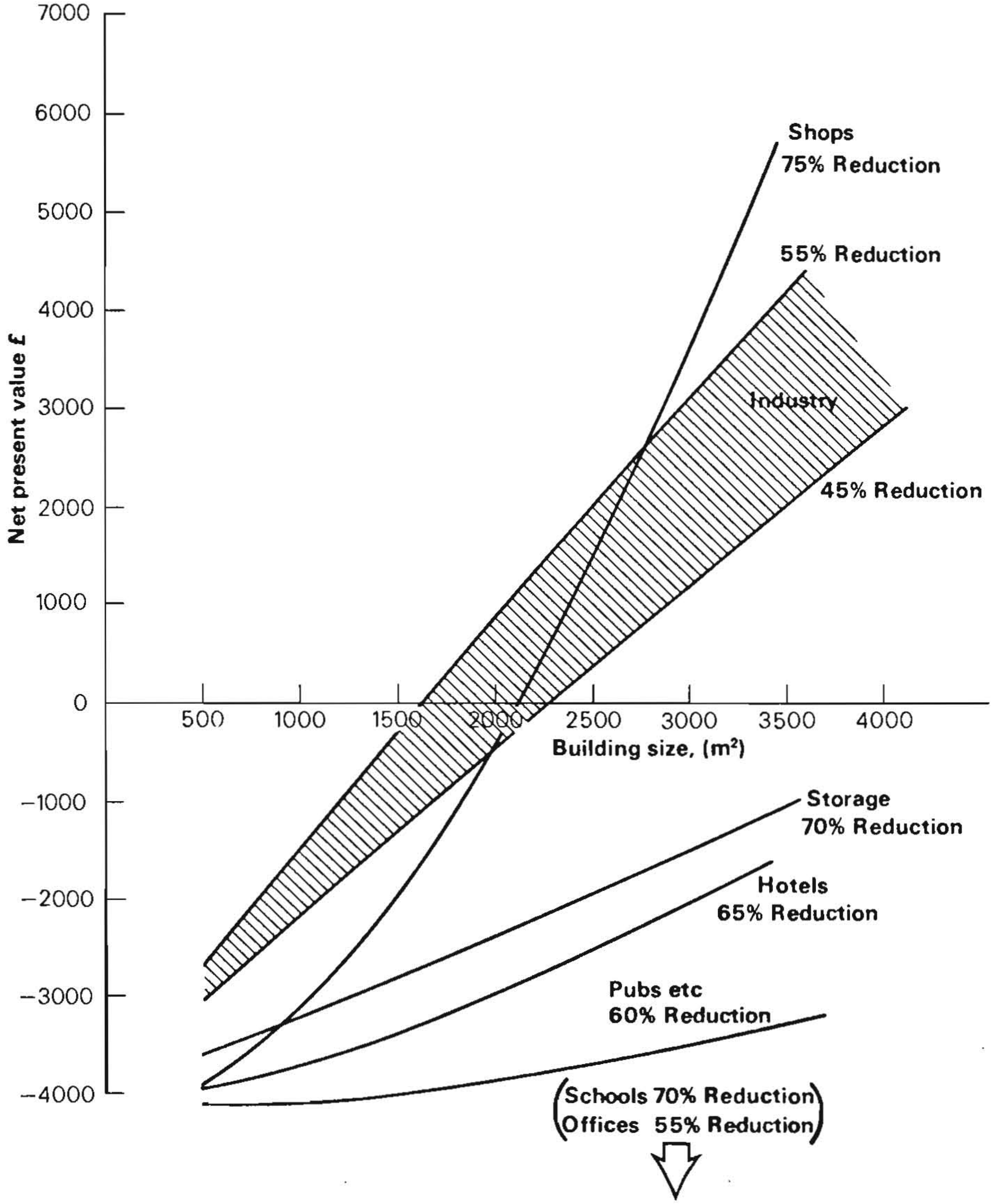
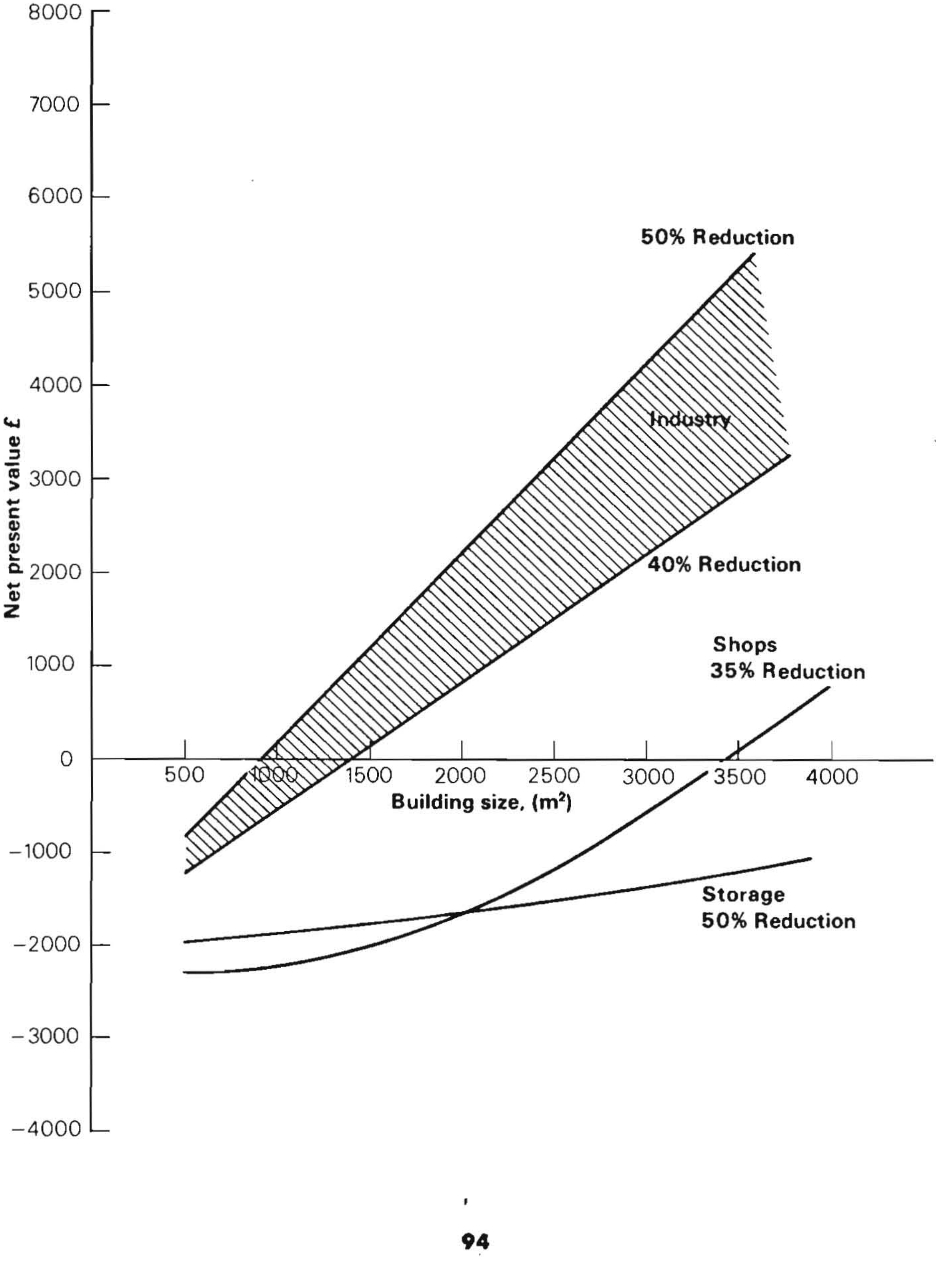


Figure 7 THE VALUE OF LOCAL ALARM DETECTORS IN DIFFERENT OCCUPANCIES



APPENDIX A   CHANGES IN THE PATTERN OF FIRES 1970-76

In this study the data used relates to different years. It has been assumed that as the characteristics of fires has not changed much over recent years, the data from separate years can be combined.

Table A1 shows some of the characteristics of fires, as given in the published fire statistics for the period 1970-76. Although there has been a change in the number of fires, the characteristics of the fires do not appear to have changed, at least within the limits of the accuracy of the calculations in the study.

TABLE A1. THE PATTERN OF FIRES OVER THE YEARS

	1970	1971	1972	1973	1974*	1976
Number of fires						
- Total	90412	89310	100081	105328	101522	95795
- Industrial	12277	11022	11241	12322	11384	10042
- Shops	4556	4225	4641	4536	4322	3952
Average fire loss (at constant 1976 prices)						
- Industrial	£8800	£10700	£9050	£1130	£9090	-
- Transport and distributive trades	£5300	£ 7100	£5200	£6600	-	-
Method of extinction						
- Proportion of fires extinguished with hosereels only	42.0%	41.0%	41.6%	41.7%	40.6%	40.2%
- Proportion of fires extinguished using main jets	17.0%	16.9%	16.9%	16.8%	16.4%	16.7%
Spread of fire **						
- Proportion of fires confined to room of origin and involving contents only	25.8%	28.2%	36.5%	35.9%	-	-
- Proportion of fires confined to room of origin, involving structure	26.1%	25.8%	13.5%	13.2%	-	-
- Proportion of fires spread beyond building	3.3%	2.8%	2.4%	2.6%	2.4%	3.1%

* Detailed fire statistics were not published for 1975.

** The published information on spread of fire was re-defined in 1972 and again in 1974.

APPENDIX B. AN EXAMPLE OF THE DATA COLLECTED IN THE SPECIAL FIRE SURVEY

The fire survey form shows the degree of detail recorded in the special fire survey. This form also shows the assessment (page 3) of the effect of different fire protection measures, and illustrates the reasoning behind these estimates.

The fire brigade K433 fire report for the same fire is also included here. The data from the larger sample of K433 fire reports was used in generalising and validating the detailed survey results.

FIRE SURVEY FORM

FIRE SURVEY

CALL NO: X

STATION X

WATCH X

DATE X

FIRE NO. X

OCCUPANCY	Industrial (Paper storage)	AGE		LEGISLATION		FOC RATING	
		NO OF STOREYS	2	TOTAL AREA (1)	2500 m²		
AREA - ROOM OF ORIGIN	~ 45 m²	POSITION OF ROOM	1st floor	USE OF ROOM	Paper storage and packing		
ACTIVITY & CONTENTS OF ROOM	Apparently unattended for, say, 30 mins before fire.						
FIRE LOAD (2)	Very high	ITEM FIRST IGNITED	paper stack	SIZE OF ITEM	up to 4 m HEIGHT	? AREA	
CAUSE OF FIRE AND RATE OF GROWTH FROM IGNITION	Unknown. Presumptive evidence for smoking materials in contact with carton papers. Initially slow development unobserved.			TIME	14.45 approx		
PEOPLE IN ROOM	0	PEOPLE IN BUILDING	28	NEAREST TO FIRE	In another room, 5-10 m away.		
PERSON(S) DIRECTLY INVOLVED IN FIRE	none						
WHO DISCOVERED	Workers						
REASON	Saw smoke coming down from outside						
SITUATION ON DISCOVERY RATE OF DEVELOPMENT	Saw flame halfway up stack in next room (B) with flames along ceiling i.e. G.R.P. Northlight not penetrated here. Appears to have been fire in first room (A) breaking through.	TIME	~ 15.08	FIRE SIZE	~ 45 m²		
EXTINGUISHERS USED	None	~~FIRE BURNT ITSELF OUT~~	~~FIRE PUT OUT~~	~~FIRE DECREASED~~	NO CHANGE	~~FIRE~~ INCREASED	~~EXTINGUISHER(S)~~ FAILED TO WORK
NO. PEOPLE USING	TIME						
SITUATION AT TIME OF CALL. RATE OF DEVELOPMENT	Apparently B/G alarm at 4 m away by exit used. Fire accellerating and men ran away. G.R.P. roof failing in next room (B).	TIME	15.11	FIRE SIZE	55 - 60 m²		
SITUATION AT TIME OF ARRIVAL. RATE OF DEVELOPMENT	Roof failed in A, B and C. Fire spreading rapidly to fill all of 1st fire section.	TIME	15.17	FIRE SIZE	150 m²		
DOORS FROM ROOM	Ordinary panel						
DISTANCE/FIRE	unknown						
LEADING TO:- (SEE "FIRE" ENVIRONMENT" ALSO)	corridor						
OPEN (WHY?)	probably shut.						
SHUT: NOT AFFECTED							
SHUT: SURVIVED (TIME)							
SHUT: FAILED (TIME)							
SHUT: BY-PASSED	✓						

CEILING	TYPE	G.R.P Northlight Roof
ROOM OF ORIGIN	REASON FOR FIRE BEYOND	flammable
FLOOR	TYPE	
ROOM OF ORIGIN	REASON FOR FIRE BEYOND	Concrete —
WALLS	TYPE	Fibre board on wooden panels
ROOM OF ORIGIN	REASON FOR FIRE BEYOND	combustible - penetrated within about 10-20 min. High surface spread of flame.

IF ROOM OF ORIGIN NOT A "FIRE ENVIRONMENT" (3) BECAUSE OF DOORS/HATCHES OPEN, ETC

AREA AT RISK (FIRE ENVIRONMENT AND USE	AREA		unknown
	NO.OF ROOMS		
AREA OF COMPARTMENT AND USE	AREA		—

FIRE PROTECTION	PRESENT	OPERATED	REMARKS
MANUAL ALARM	✓	✓	
HEAT DETECTOR	×		
SMOKE DETECTOR	×		
SPRINKLER	×		
LOCAL ALARM ONLY	✓	✓	
24 HR MANNED POINT (4)	✓	✓	– 999
DIRECT LINE OR AFA	×		
OTHER/ (STATE WHICH)	×		

LEGISLATIVE REQUIREMENTS	EFFECT ON FIRE SPREAD

ACTUAL DAMAGE(S)	CONTENTS	STRUCTURE
FIRE	~ 1000 m²	~ 750 m²
HEAT	1500 m²	-
SMOKE	?	–
WATER	1000 m²	-

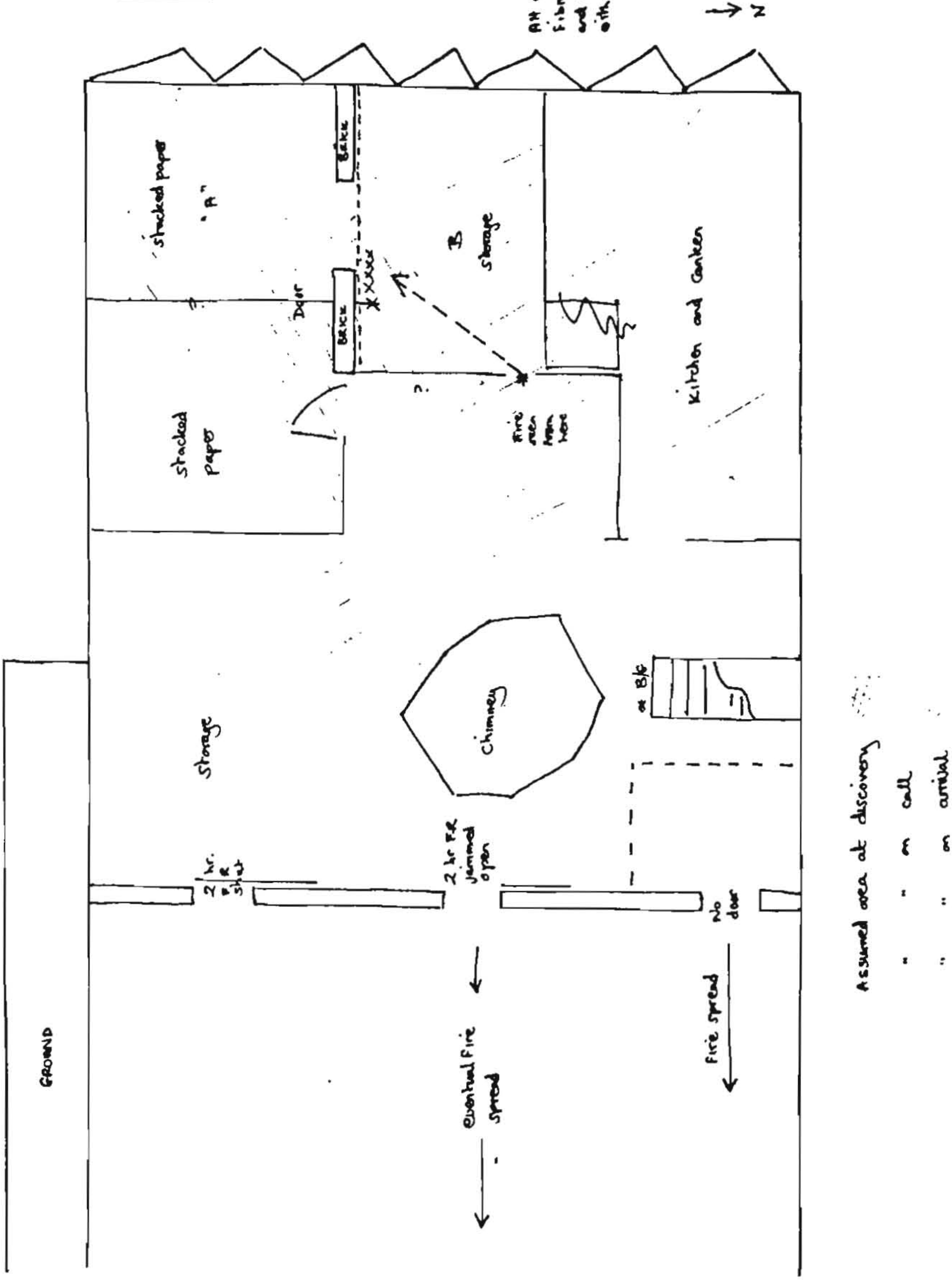
ASSUMED DAMAGE (FIRE ONLY)

F.P. PACKAGE	AREA	REASONS
MEANS OF ESCAPE WITH (A) 30 : 20 FIRE - CHECK DOOR, EXTINGUISHERS MANUAL ALARM	1000 m²	Actual situation
(B) AS (A) PLUS SMOKE DETECTOR WITH LOCAL ALARM ONLY	< 1 m²	If smoking is correct cause, fire could have been detected in primary stages.
(C) AS (B) PLUS DIRECT LINE OR AFA TO F/B	< 1 m²	——— " ———
(D) SPRINKLERS WITH DIRECT LINE OR AFA TO F/B	1–2 m²	sprinkler may have had difficulty at base of stack but should have confined fire. Roof may not have become involved and spread fire.
(E) COMPARTMENTATION OF ROOM OF ORIGIN TO 60 MIN WITH SC BSS 'FIRE CHECK' DOORS	≤ 45 m²	Proper F.R of walls i.e. plaster board would have at the worst confined fire to room of origin.

	NUMBER OF SELF EVACUATIONS OR ESCAPES I				NUMBER OF ASSISTED RESCUES/ESCAPES II				NUMBER OF FATALITIES III				NUMBER WHERE ESCAPE, EVACUATION NOT APPLICABLE IV
	TOTAL	NO EXPOS	SMOKE ONLY	HEAT AND FIRE	TOTAL	NO EXP.	SMOKE ONLY	HEAT AND FIRE	TOTAL	NO EXP.	SMOKE ONLY	HEAT AND FIRE	
NO INJURY		28											
SMOKE EFFECTS													
HEAT/BURNS													
FRACTURES													
OTHER													
TOTAL		28											

PAGE 4

SKETCH PLAN (NOT TO SCALE)



REPORT OF FIRE No. K433 (7th Revision—3rd Impression)

X *Fire Brigade/Fire service | Call No.

Part 1

Date and Day of Call X

Additional particulars to follow on form K434.* No additional particulars to follow.*

Division, etc. X Station X

* {For Counties (E. & W.) only—County District (i.e., Non-County Borough, U.D.C. or R.D.C.) X
For Scotland and N. Ireland—Administrative Area in which Fire occurred

Part II—Call

1. Address of Fire X
2. Name(s) of Occupier(s) X
3. Trade(s) or Business(es) carried on:
Paper and stationery distributors

Where fire started: 1st floor rear stationery store.

Where fire spread to: whole of 1st floor

4. Method of Calling: (a) W.F.B. —
(b) F.B. A.M.C
5. Discovered by Workmen inside
6. Weather Dry and clear
7. Road condition Dry
8. Wind Light
9. Time of Discovery 15.09
10. Time to Call to W.F.B.
11. Time of Arrival of W.F.B.
12. Time of Call to F.B. 15.11
13. Time of Arrival of F.B. 15.17
14. Time under control 16.39
15. When last F.B. Appliance returned to Station
(a) Date X
(b) Time 12.26
16. Risk Category B

Part III—Particulars of Fire

1. SUPPOSED CAUSE:
Carelessly discarded smoking materials igniting paper in storage

2. PARTICULARS OF PROPERTY INVOLVED: Type No. 4 Approximate date of building construction or manufacture 1890

DESCRIPTION:
A building of two storeys, brick walls, 1st floor timber, ground floor concrete, north light roof part slate part glass and part GRP replacing glass approx 170' x 90'

3. PARTICULARS OF CONTENTS:
As incidental to paper and stationery distributors

4. EXTENT OF FIRE
(i) Fires in Buildings.

CONFINED TO {room of origin / floor of origin / building of origin Yes / roof or roof space}

EXTENDED TO {adjoining buildings / †separate buildings / other hazards}

(ii) Fires other than those in buildings.
CONFINED to hazard in which fire started

EXTENDED TO {†buildings / other hazards}

5. DESCRIPTION OF DAMAGE:
Severe by fire to whole of first floor by heat and water to 90% of contents of ground floor.

6. DEVELOPMENT OF FIRE: Assisted by combustible floor, wall, ceiling, roof lining*

7. SPRINKLERS:
(i) ~~*Hand operated system installed~~
~~*Automatic system installed~~
*Not installed
{In room or section}
(ii) Failed to operate because
(iii) ~~Operated,~~ ~~heads being actuated, and (a) *Controlled fire. (b) *Extinguished fire.~~
(c) ~~*Did not control fire because~~

*Delete as necessary. †See separate form(s) K.433 marked

8. FIRE PROTECTION APPLIANCES OR DEVICES OTHER THAN SPRINKLERS OR PORTABLE HAND OPERATED APPLIANCES:

9. METHOD OF EXTINGUISHING THE FIRE:

(i) If tackled before the arrival of F.B. give details (including methods used by Works Fire Brigade):

(ii) Method used by F.B.:

(iii) If immediate water supply was inadequate, give reason and details of any relay brought into operation:

Part IV Rescues, Escapes

Name(s)	Sex	Age (years)	Method of rescue or escape	Person effecting rescue

Part V Casualties*

†Name(s)	Sex	Age (years)	Address(es)	Nature of injury	If injuries prove fatal, cause of death

*Other than those requiring First-Aid treatment only †For F.B. personnel add (F.B.) after name

Part VI—Attendance

1. F.B. APPLIANCES:

(Give Fire Brigade (name suitably abbreviated), Division (if applicable,) and Station (number or name suitably abbreviated) from which the appliances attended, followed by the total number of appliances in brackets, e.g., "L.C.C. B. 26 (2)." Relief appliances are not to be included.)

P.E. .... WR.T. ....

PUMPS ....

T/L. (Mech.) ....

T/L. (60' H/O.) ....

Give particulars of other F.B. appliances:

2. APPLIANCES OTHER THAN F.B. ....

3. F.B. PERSONNEL above rank of Station Officer† attending before receipt of "stop" message (staff, visiting and relief officers need not be shown). †Note—When the officer in charge of the fire is of Station Officer rank, or below, his name should be entered.

Designation of Station or Headquarters to which attached	Rank	Name

4. TOTAL NO. OF PERSONNEL ATTENDING: (a)Whole-time:— (b) Part-time:—

Part VII—Remarks

Signature ....

Officer in charge of Station

Date ....

904244 Dd 15056 1M 4/74 GP