Real fire data

Fires in non-residential premises in London 1994-1997

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Report 7003

Real Fire Data

Fires in non-residential premises in London 1994-1997

Digital version

Stefan Särdqvist

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Lund 1998

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Abstract
A detailed fire investigation of most fires occurring in the greater London area has been underway since 1994. The present study concerns 307 fires in non-residential buildings there between 1994 and 1997. The cause of the fire, the means of discovery, the times to detection, to arrival of the fire brigade and to extinguishing the fire, the size of fire and the process of extinguishing it are investigated.

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Summary

A detailed investigation of most fires occurring in the greater London area has been underway since 1994. The present study concerns reports from 307 fires in non-residential buildings there between 1994 and 1997. The cause of the fire, the means of discovery, the times to detection, to arrival of the fire brigade and to extinguishing the fire, the size of fire and the process of extinguishing it are reported.

The main conclusions drawn were as follows:

- Two-thirds of the fires were reported to be accidental and the remaining third to be of deliberate origin.
- Half of the fires were discovered by someone seeing or smelling smoke.
- The automatic fire alarm failed in one-fifth of the fires in which such a system was present.
- No support was obtained for the hypothesis that the time from ignition to when the fire brigade intervened is correlated with the fire area.
- At half of the fires, the final area of fire spread was equal to the area at discovery, and at three-quarters of the fires, the final area of fire was equal to the area when the fire brigade arrived.
- Both the water-flow rate for extinguishing a fire and the water application time was found to be proportional to the square root of the fire area. The total water demand was proportional to the area of the fire.
- Fires were contained or extinguished by an automatic sprinkler system in 17 of 21 fires, where such a system was present. Only 13 fires were contained by one or two sprinkler heads, fires where the system was in order, covered the fire area and where no flammable liquids were present.
- The data collected by the London Fire Brigade proved to be of great value in understanding relations between the work of a fire brigade and the threat due to the fire.
- The present study concerns only a part of the material available at the London Fire Brigade, there being more parameters yet in the database to be investigated, such as fires in residential premises or problems concerning the evacuation process.

Sammanfattning

Sedan 1994 görs en fördjupad brandorsaksutredning vid de flesta bränder i London. Denna studie bygger på utredningar från 307 av bränderna som inträffat i byggnader utom bostäder i London under perioden 1994-1997. Bland annat redovisas brandorsak, upptäckssätt, tid för upptäckt, insats, och släckning, brandens storlek och släckförlopp.

I rapporten visas att:

- En tredjedelar av bränderna angavs vara anlagda. (kapitel 4)
- Hälften av bränderna upptäcktes genom att någon såg rök eller kände lukten av rök. (kapitel 5)
- Larmet fungerade inte som avsett vid en femtedel av de bränder där det fanns automatiskt brandlarm i byggnaden. (kapitel 5)
- Något samband mellan brandskadans storlek och insatstiden kunde inte hittas i materialet. Det finns alltså inga belägg i materialet för att en lång insatstid skulle ge en stor skada. (kapitel 6)
- Vid hälften av bränderna var brandens slutliga storlek lika med dess storlek vid upptäckten. Vid tre fjärdedelar av bränderna blev den totala brandskadan lika stor som den var vid brandkårens framkomst. I dessa fall hade alltså brandspridningen begränsats redan innan brandkåren var på plats, möjligen beroende på bränslets mängd och fördelning. (kapitel 6)
- Vid släckinsatserna växer både det använda vattenflödet och den effektiva släcktiden (den tid som vatten sprutas) med roten ur brandytan. Det totala vattenbehovet växer med brandytans storlek. (kapitel 7)
- Bränderna släcktes eller begränsades av det automatiska sprinklersystemet i 17 av 21 bränder, där ett sådant fanns installerat. Endast 13 bränder kontrollerades av ett eller två utlösta sprinklerhuvuden. Gemensamt för dessa bränder var att systemet var inkopplat, väldimensionerat, samt att inga brännbara vätskor var inblandade. (kapitel 7)
- Den databas som finns vid Londons brandkår visade sig ge ett värdefullt bidrag till förståelsen för hur räddningstjänstens insats påverkar brandförloppet.
- Den aktuella studien innefattar endast en del av materialet i databasen hos Londons brandkår och det finns fler parametrar som väntar på att bli studerade, exempelvis rörande bränder i bostäder, utrymning vid brand m.m.

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1 Background

The present study was carried out for exploring the possibility of using data from real fire investigations as a basis for developing models to predict the outcome of fire-fighting operations. Parameters of special interest for examining the relationship between the threat a fire poses and the capability of the fire brigade are the development of the fire, the actions of the fire brigade and the performance of the active and passive fire protection systems present.

There is a genuine lack of information regarding real fires. In the ambitious program for the gathering of information on fires which the Swedish Rescue Services Board conducts, quantification is also lacking, the size of a fire only being assessed qualitatively, in terms of whether the fire was limited to the object ignited first, to the room or to the fire compartment of origin, or whether the fire spread further., Thus, insufficient information is available from Swedish sources for determining the capability of fire brigades.

Some years ago, the Home Office in England sent out a note on improving the work of the London Fire Brigade. The background to this was the fact that the most common cause of fire listed was that of the cause being ”unknown”. For this reason, the London Fire Brigade has investigated major fires ever since 1994. In the material collected there, the parameters whenever possible are quantified. The findings obtained are stored in an Access database.

The major aim in developing this database has been to gather information on the causes of fires. The large amount of information the database contains makes it possible to use the database for other scientific aims as well. Accordingly, there are many questions regarding the performance of fire brigades which the material from the London Fire Brigade is able to illuminate. One such question is that of how the time that elapses from ignition to fire brigade intervention affects the size of the area that is damaged. There are two major reasons for fires in buildings becoming large, one being the construction and contents of the building, and the other the limitations present in the fire brigade’s fire-fighting operations. Another question is that of water needs, or more specifically the water flow required for extinguishing fires of different size. Still another question is that of the performance of different fire safety systems, such as sprinklers and automatic fire alarms.

The present study is concerned primarily with four main phases of a fire:

- The ignition phase or ignition process. The cause of a fire and the question of whether it was accidental or deliberate are considered here.
- The discovery of the fire, the performance of automatic fire alarms being of particular interest here.
- Fire growth, which is perhaps the most important aspect of a fire. Problems of detection, response and extinguishing times and fire-growth rates, are dealt with here.
- The fire-extinguishing process. Problems related to the demand for extinguishing media and for other resources, as well as the performance of automatic suppression systems, such as sprinklers, are considered here.

2 The Real Fire Data Base

At the time when the data analysis for the present report was carried out, the Real Fire Database at London Fire Brigade contained basic information on 11405 fires that had occurred during the period of January 1994 to June 1997. 2225 of these had been investigated by a Fire Investigation Unit. For these fires, extensive material was available concerning the fire itself, the scene of the fire and the fire-fighting operations. Although most of the information is available digitally, some of it, such as drawings of the room of origin are only available in paper format.

There are five Fire Investigation Units in the greater London area. Each consists of two fire investigators with access to a specially equipped vehicle. The unit is alarmed automatically of the occurrence of two types of fires:

1. Four-pump fires and higher, i.e. fires to which four or more fire engines are sent to the scene.
2. ”Persons reported” fires, i.e. fires for which, at the time they are discovered, one or more persons are reported to be inside the building in question.

There are also situations in which the Fire Investigation Unit is not alarmed automatically, but in which the Incident Commander shall request the Unit’s attendance. These are situations in which any of the following person-related, operational or fire-safety-system considerations or considerations concerning types of premises are involved:

Person considerations
- *fatalities,*
- *serious injuries,*
- *rescues performed*
- *large numbers of persons evacuated,*

Operational considerations
- *fire doubtful, suspicious or of unknown origin*
- *of a type or frequency involving a particular pattern*
- *hazardous materials involved*
- *explosimeter employed*
- *water shortage experienced*
- *caused by faulty gas/electric appliances*
- *alternative means of lighting, heating or cooking used due to disruption of the power supply*
- *possibility of the fire re-kindling (re-ignition)*

Fire-safety-system considerations
- *buildings with automatic fire detection or fire suppression equipment*
- *failure of the fire safety system*
- *fire safety infringements are noted*

Considerations concerning types of premises
- *premises subjected to Section 20, London Buildings act, 1939.*
- *premises holding a Petroleum Licence*
- *places of public entertainment*
- *railway premises*
- *blocks of flats of three or more storeys*
- *commercial/industrial premises*
- *HMOs*
- *hotels, hostels and boarding houses*
- *hospitals*
- *residential care homes*
- *children’s homes*
- *schools*

The data used was retrieved using a number of different forms, as shown in Table 1. Not all the forms are used for all of the fires and not all of them are included in the database.

Table 1. The different forms used by the Fire Investigation Team. Most of the forms are presented in the figures on the following pages.

Form	Types of fires	Figure
FIT/1	Fire brigade report to the police.	-
FIT/2	Fire investigation unit samples for laboratory examination.	-
FIT/3	Fire investigation statistical report with information of incident details, location of fire, supposed cause, damage and attending resources.	1 - 4
FIT/4	Monthly totals.	-
FIT/5	Notifiable fire report on fires of specific interest.	5
FIT/6&7	Report to coroner.	-
FIT/8	Witnesses for court or tribunal.	-
FIT/9	Inquest report.	-
FIT/10	Fire investigation unit call slip.	-
FIT/11	Summary of fire investigation.	6
FIT/12	Fire scene details and diagram to show the room/space of origin. Boundaries and breaches.	7
FIT/13	Fire spread analysis.	8
FIT/14	Smoke spread analysis.	9
FIT/15	Initiation and development analysis.	-
FIT/16	Fire suppression analysis.	10 - 11
FIT/17	Fire detection analysis.	12
FIT/18	Fire-fighting facilities analysis.	13
FIT/19	Occupant egress analysis.	14
FIT/20	Performance assessment.	15

The data from most of the forms is stored in an Access database and is included on the forms shown in Figures 1 - 15. The fires are recorded using a unique-incident number, appearing at the upper right corner on the forms. (incident 999999 is a dummy and is not included in the statistics). To prevent the identification of specific cases, the forms from different incidents are shown.

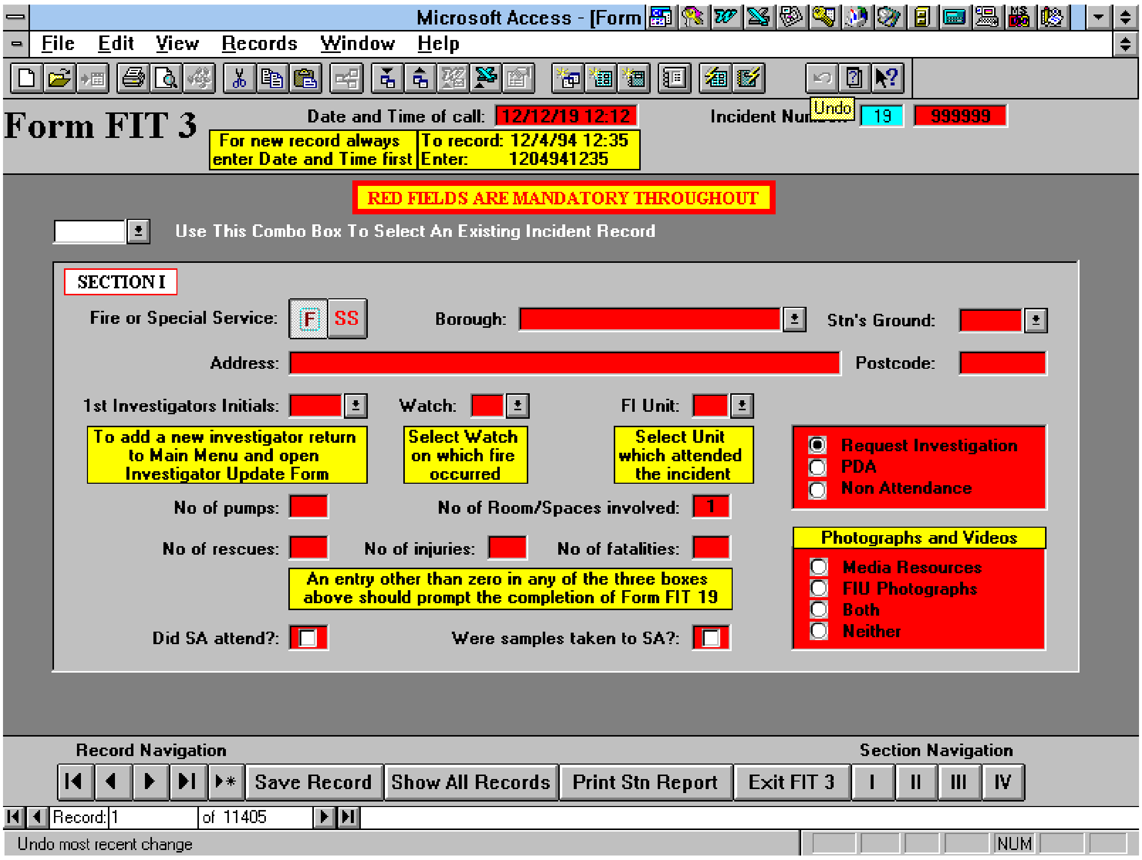


Figure 1. The first section of four in FIT/3.

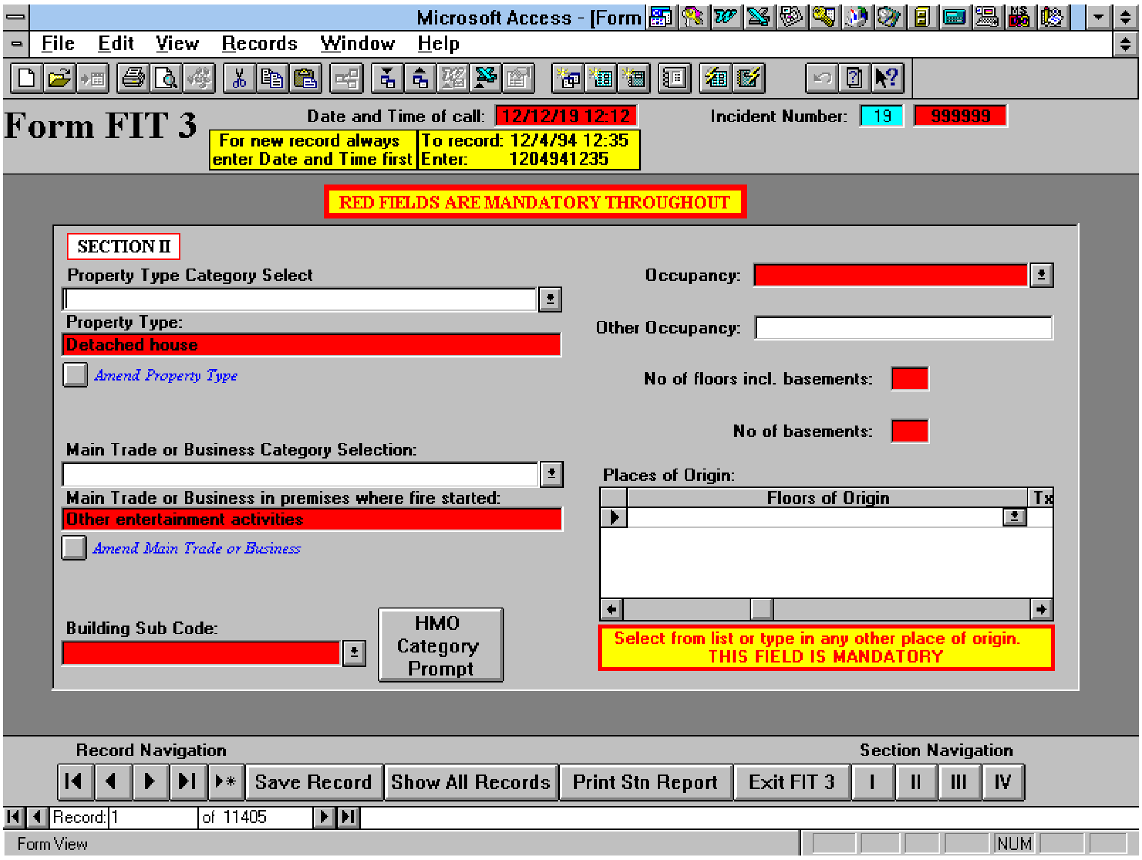


Figure 2. The second section in FIT/3.

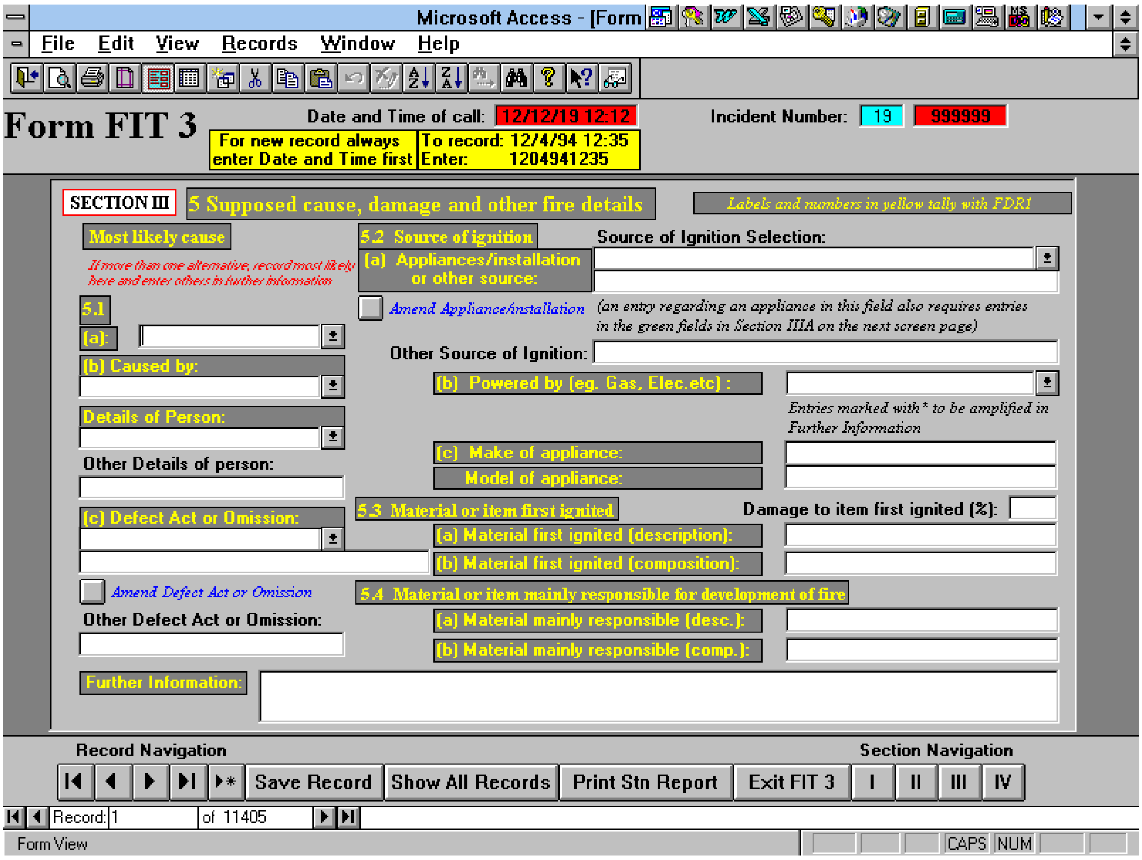


Figure 3. The third section of four in FIT/3.

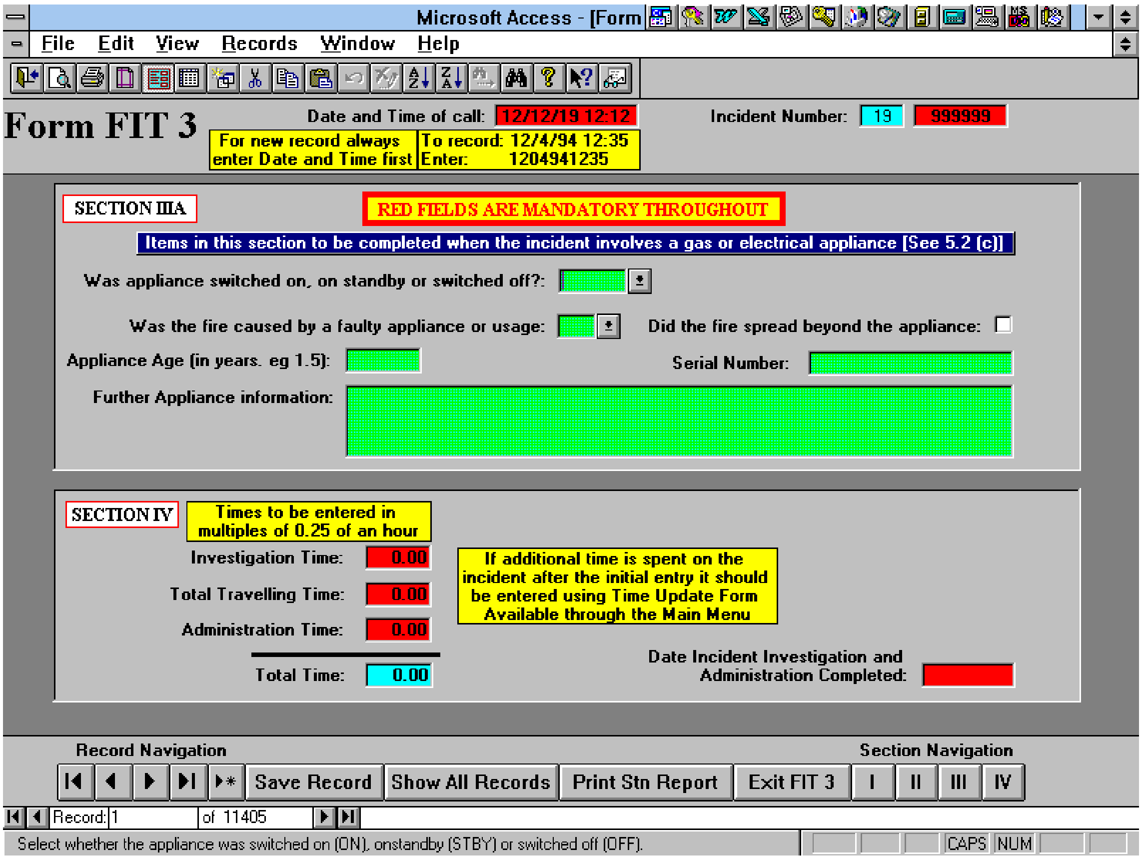


Figure 4. The last section of four in FIT/3.

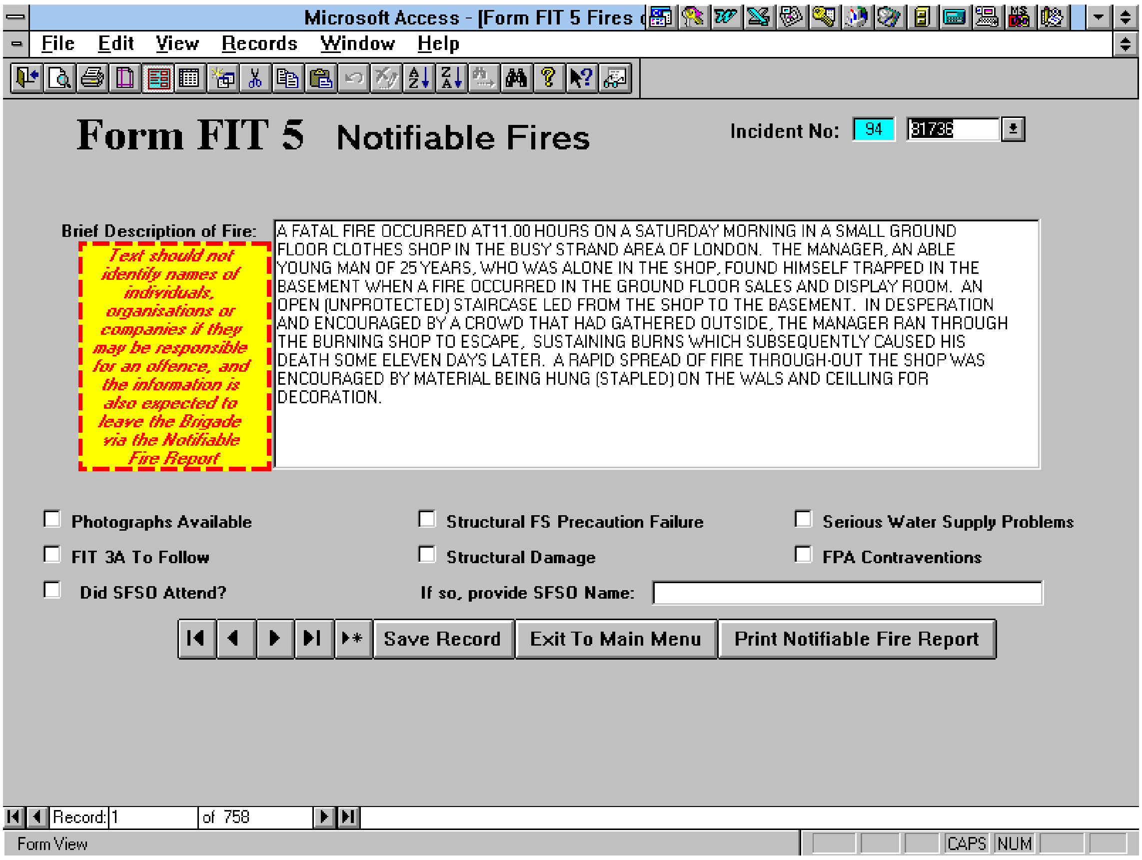


Figure 5. FIT/5, report on notifiable fires.

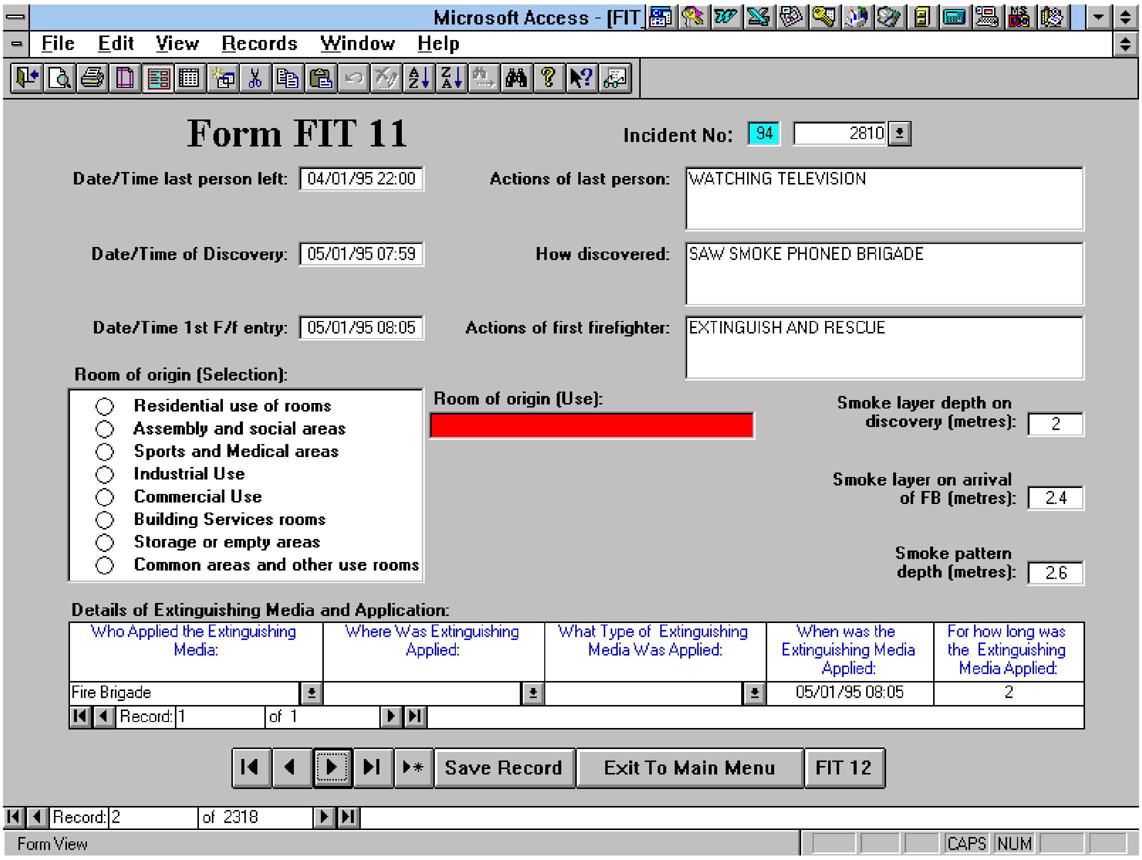


Figure 6. FIT/11, summary of the fire investigation.

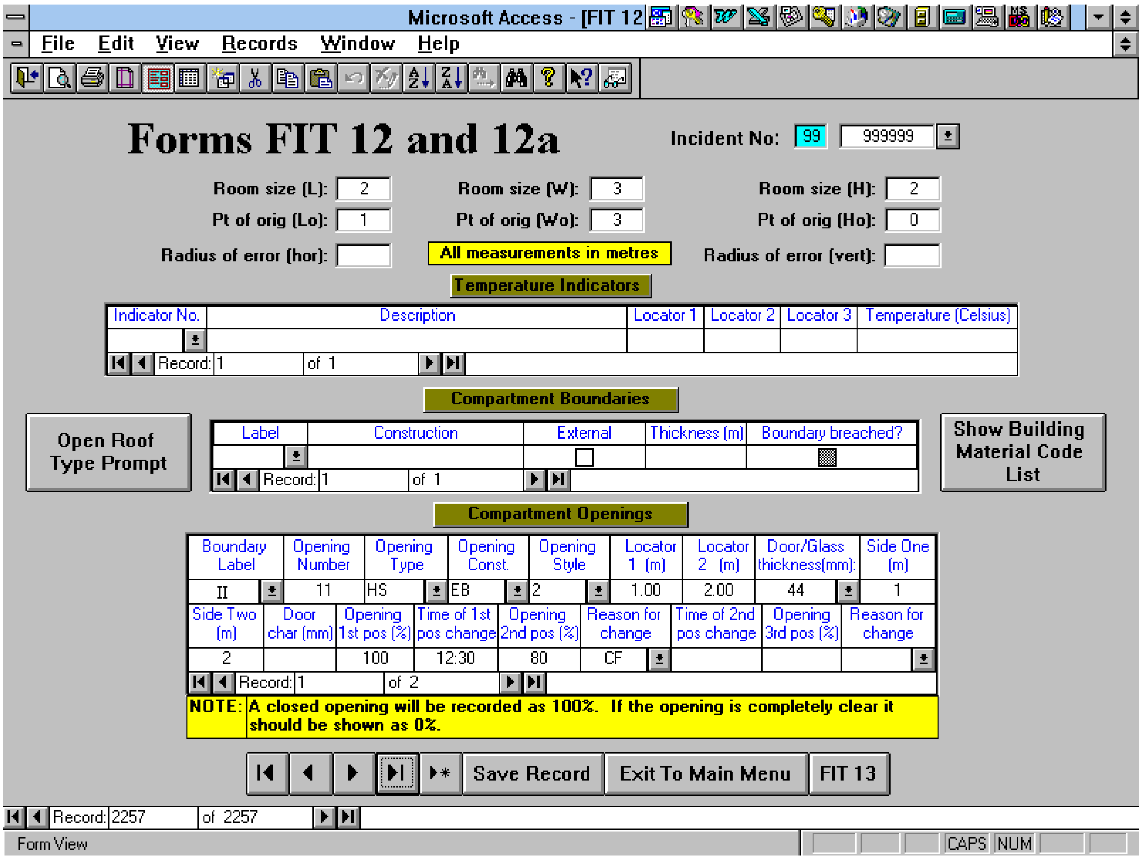


Figure 7. FIT/12, details of the fire scene.

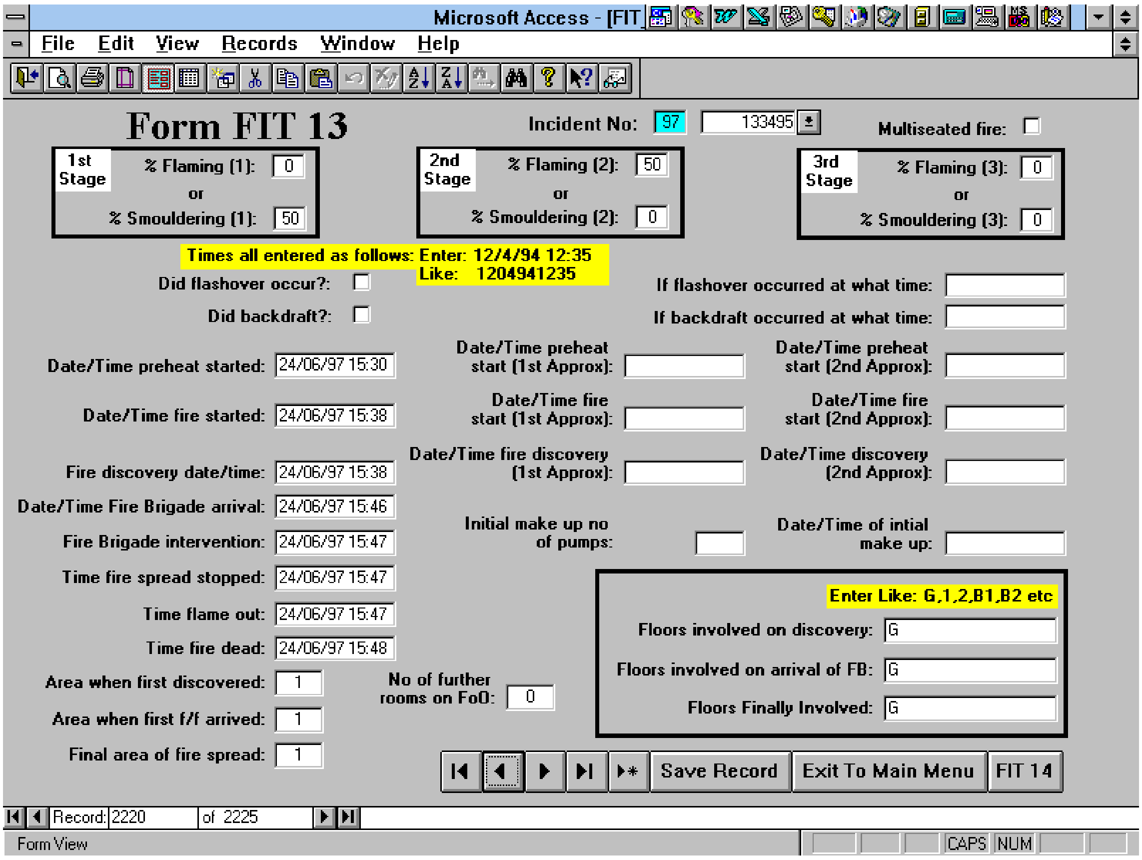


Figure 8. FIT/13, fire spread analysis, with fire area and times for different events.

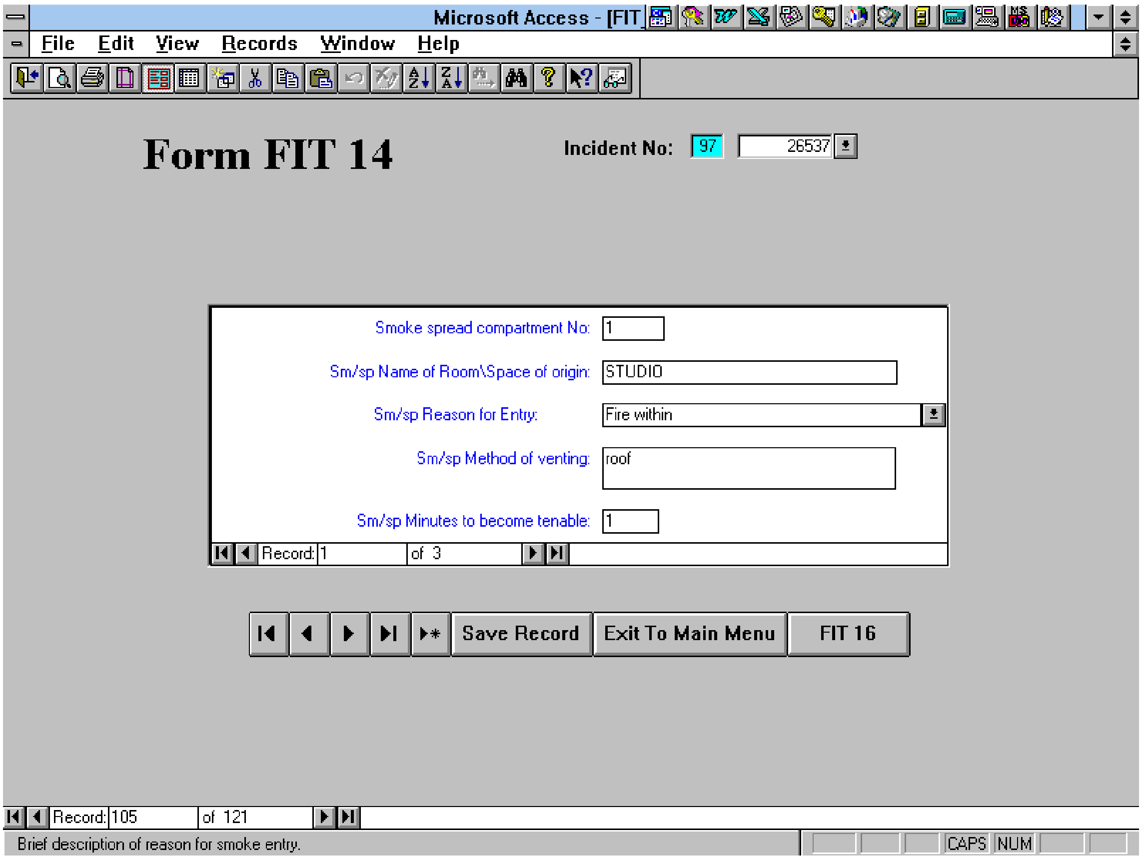


Figure 9. FIT/14, analysis of the smoke spread.

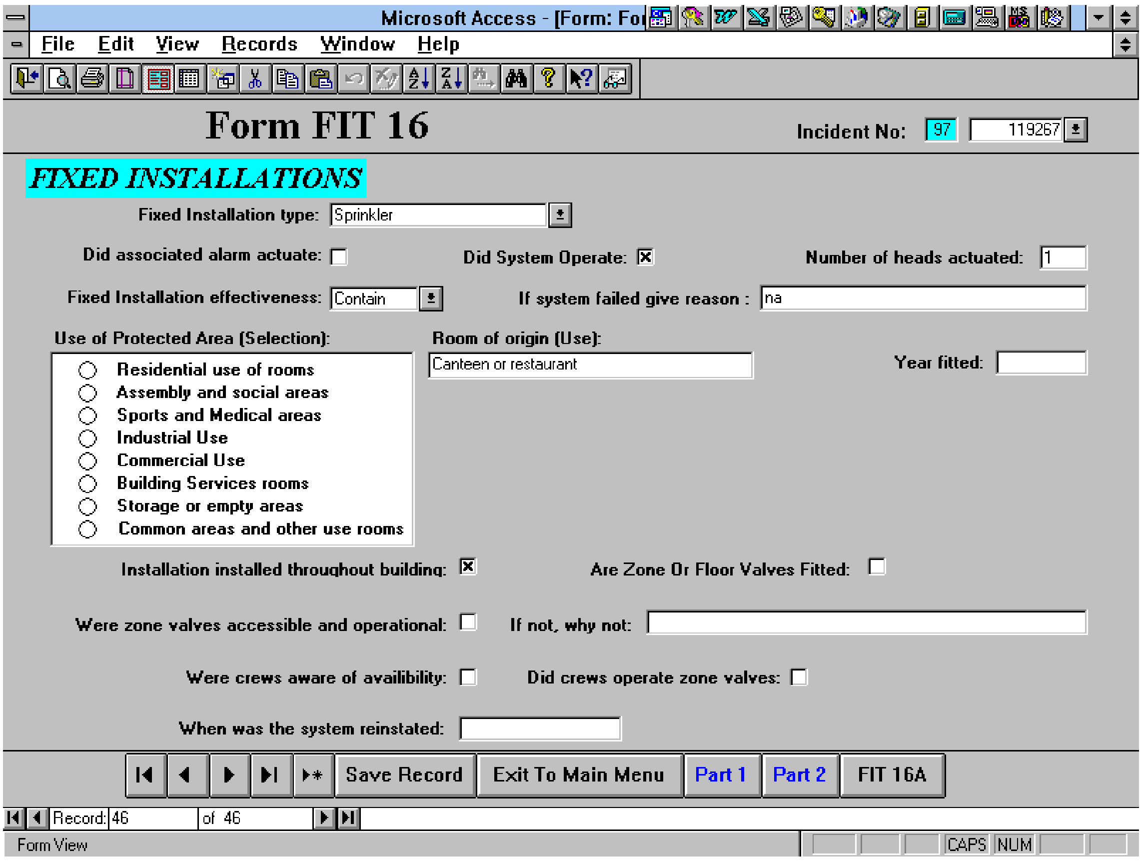


Figure 10. The first of two forms in FIT/16, fire suppression systems.

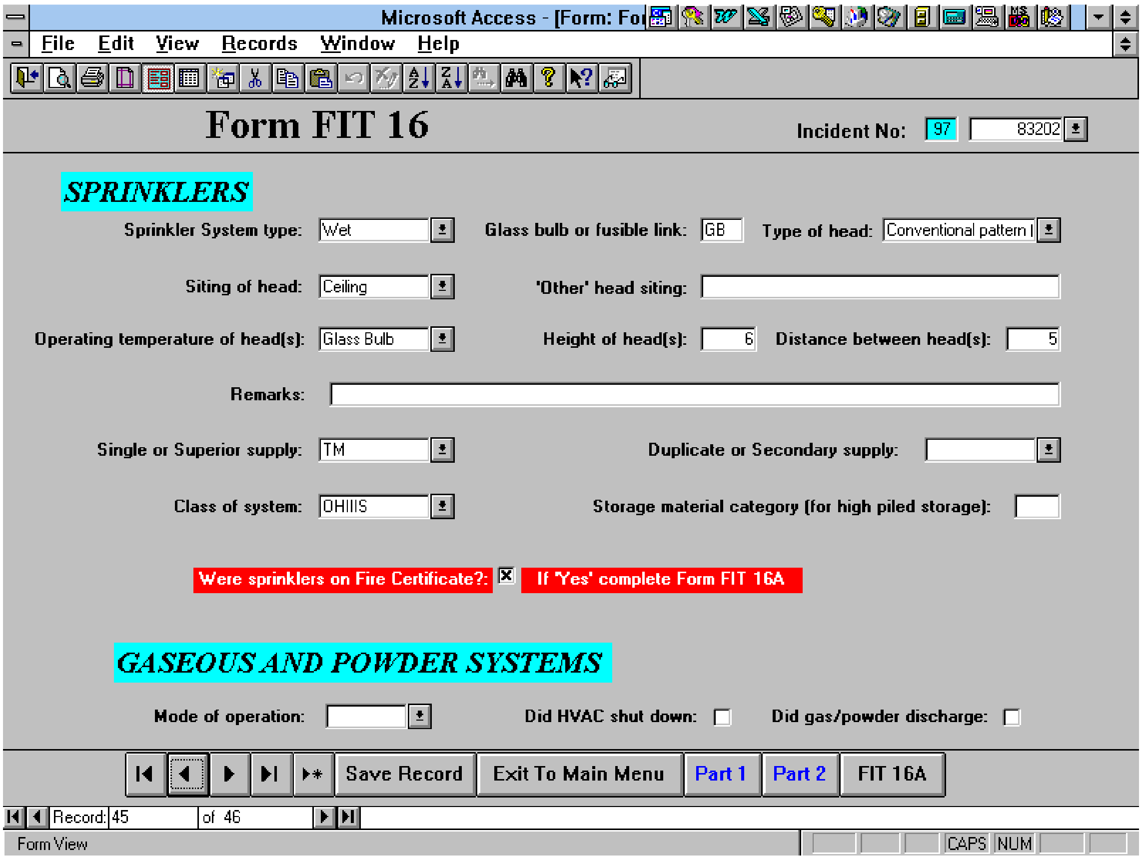


Figure 11. The second of two forms in FIT/16, fire suppression systems.

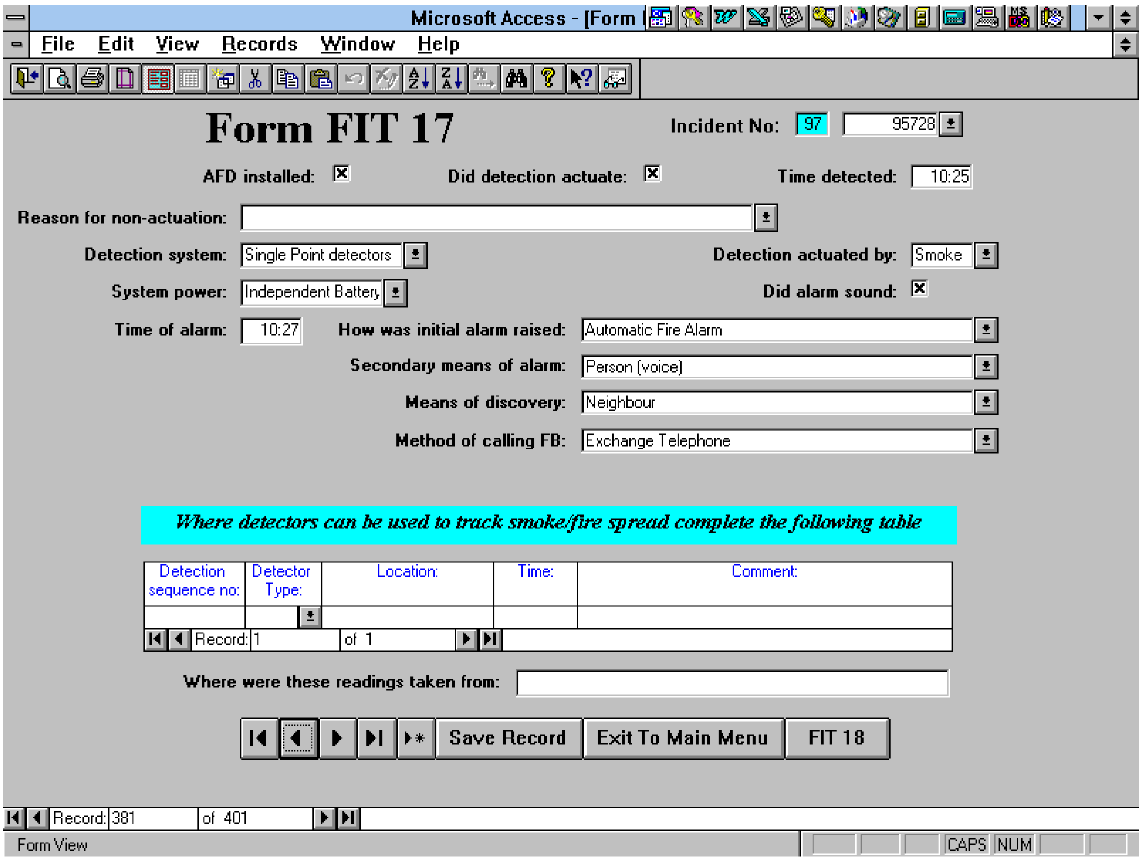


Figure 12. FIT/17, fire detection systems.

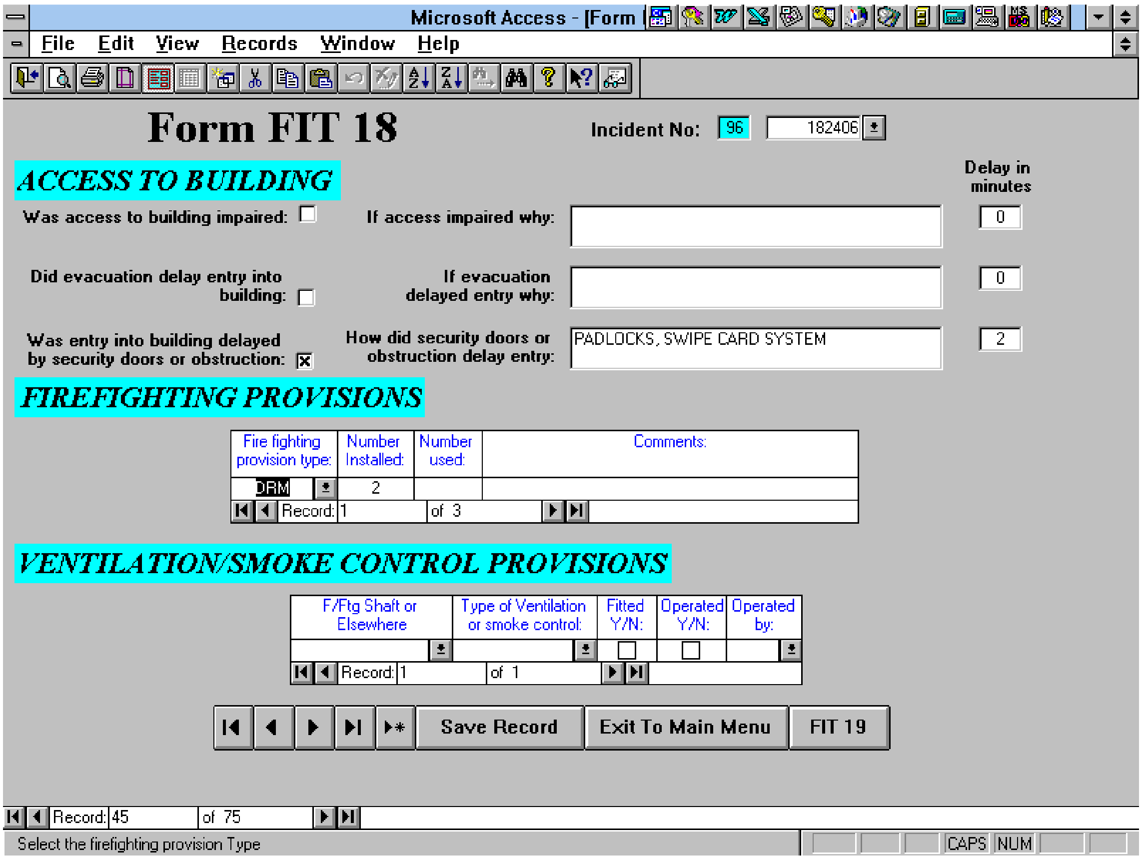


Figure 13. FIT/18, on-scene fire-fighting facilities.

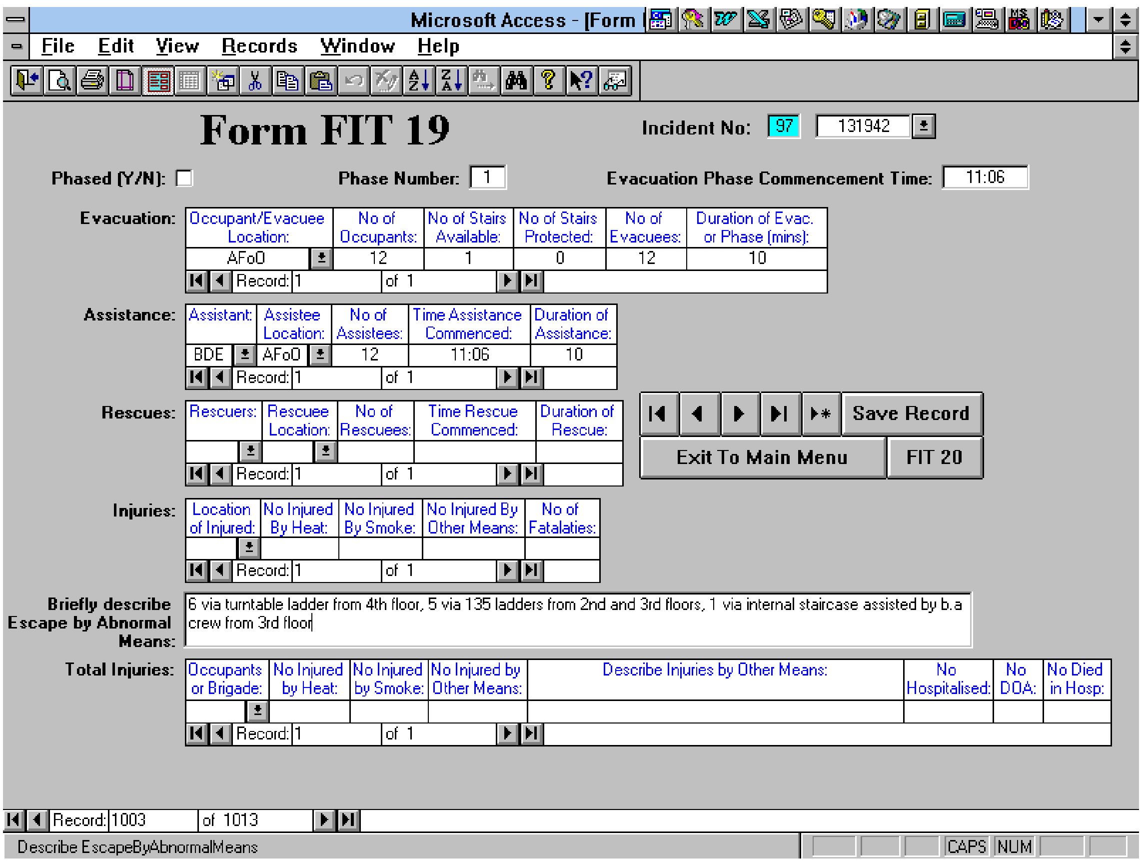


Figure 14. FIT/19, egress analysis.

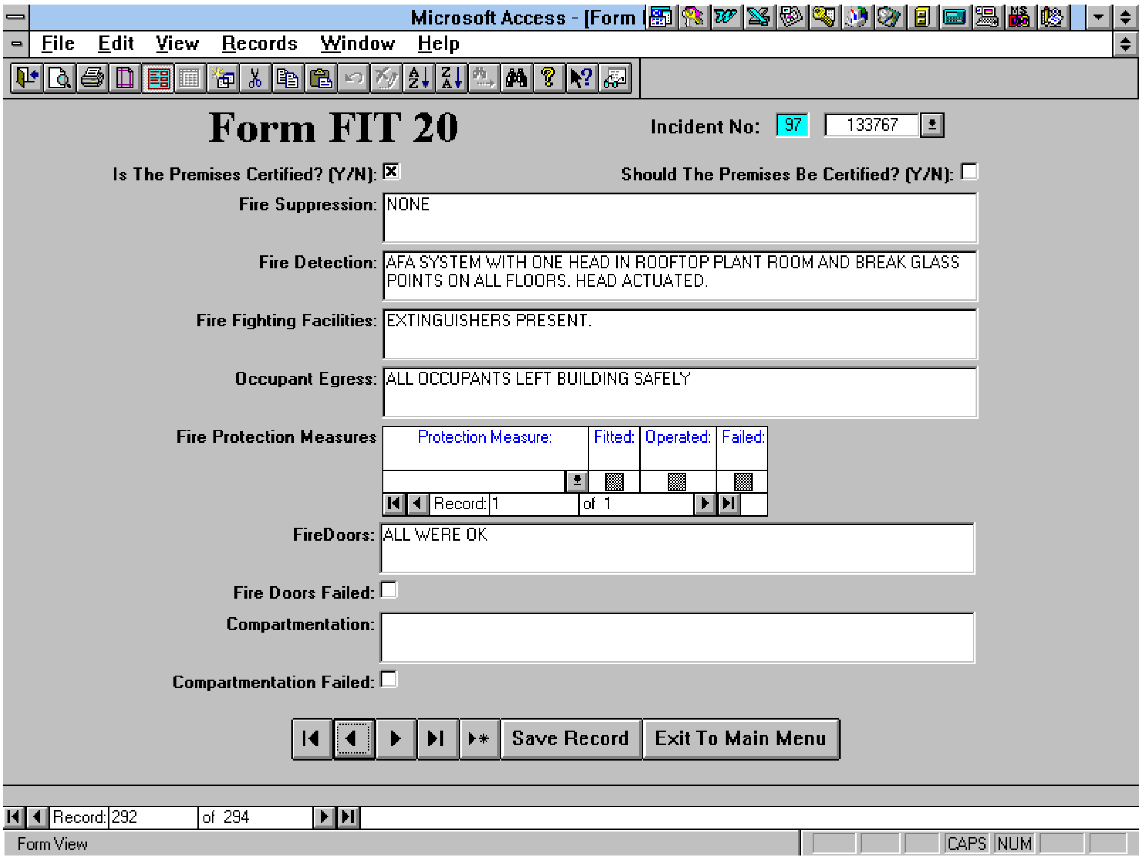


Figure 15. FIT/20, assessment on overall performance.

3 Limitations

Although data from all types of fires in London were available, the study is limited to fires in certain types of premises. In the database, the premises are classified in terms of six main categories:

1. Mobile premises
2. Public and commercial premises
3. Schools and hospitals
4. Residential premises
5. Industrial premises
6. Outdoor premises

Included in this study are (2) Public and commercial premises, (3) Schools and hospitals, (5) Industrial premises, and one subgroup from (4) Residential premises, namely Hotels and boarding houses. Mobile (1) and Outdoor (6) premises are not included. This resulted in the selection of 307 fires in non-residential buildings. In some parts of the study, an additional selection was made, e.g. of fires in which a sprinkler or an automatic fire detection system was present or for which the process of extinguishing the fire had been analysed.

All the fires have been decoded, making it impossible to identify individual fires in the material.

The study is limited to one-parameter correlations, i.e. between the time for detection or intervention and the final area of the fire spread, or between the water-flow rate and the area of the fire. The report describes only the data from the fires selected, no comparison being made with other sources.

The study concerns mainly fire-fighting, rather than search and rescue. Domestic premises, which are those premises in which the threat to life is greatest, are excluded. Thus, more information is available than used here, and the material allows other aspects than those examined to be studied.

In view of the huge amount of data stored, the occurrence of certain errors is more than likely. All obvious errors in the data have been corrected, such as a fire which occurred in January having its time of occurrence specified as being in October (recorded as month 10 rather than month 01). Only a small number of cases have been discarded, namely those in which the data does not make sense. Also, one should bear in mind that all the data have been filtered through the fire investigators. This explains why the area of the fire as given for the time of arrival of the fire brigade is always larger than, or similar in size to that listed for the time of discovery of the fire, despite the area having been estimated by different persons. Normally, persons would tend to differ somewhat in their estimates.

Commonly, it is smoke that produces the greatest damage, both to humans and to property. Nevertheless, the damage is only given in the database as the area of fire-spread. Other types of damage, such as damage due to smoke or to water are thus not included in the study.

The material concerns only fires that occurred in London. Thus, the results do not necessarily apply to other places. There may be considerable differences, for example, between London and elsewhere in England, as well as between England and other countries, in the construction and content of buildings. There may also be differences between the London Fire Brigade and other brigades, in England and elsewhere. Although this poses interesting questions, these cannot be answered until comparable statistics are available from other places as well.

4 Ignition

One of the main reasons for the database being established was that previously, the designation ”not known” was that most commonly given as the cause of ignition. Due to the nature of fire, evidence regarding the cause of it is often not to be found afterwards. There are examples in the history of fires in which two competent fire investigators have reached quite different conclusions regarding the cause of one and the same fire.

Therefore, it can only be stated that the ignition source and the cause of fire as registered in the database are the most likely appearing ones. If an investigator comes up with more than one possible ignition source, he selects one which appears the most likely. This means that some of the causes are probably wrong, yet those taken can be seen as representing the best assessment available, since there are fires in which there is no possibility of determining the cause with any degree of certainty. In the study, the number of fires of unknown cause is small and most of them stem from the initial period of using the database.

4.1 Accidental or deliberate

Caused by in the fire investigation form can mean either *Accidental* or *Deliberate*. A third option is *Not known*. Of the 307 fires selected, 200 or 65% of them are believed to be accidental and 100 or 32% of them to be deliberate. The cause was unknown in only 7 of the fires.

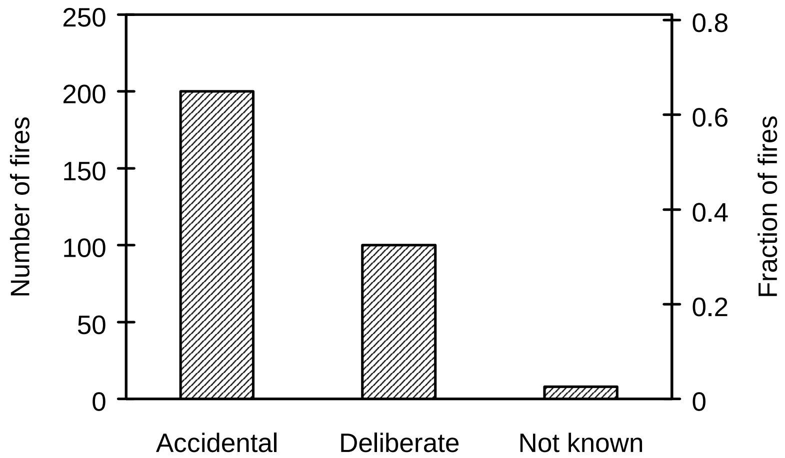


Figure 16. Two-thirds of the fires in the database are believed to be accidental and one-third deliberate.

Whether a fire is deliberate or accidental has an impact on the final size of the fire, as shown in Figure 17. Although the distribution of the areas involved appear to be about the same for the two, the average size is larger in the case of the deliberate fires. It is not clear, however, whether this is due to a number of accidental fires that are of small to medium size being included. Since the number of large fires (e.g. with a burned area of larger than 50 m²) is quite small, for this type of fire, no statistically significant conclusions can be drawn.

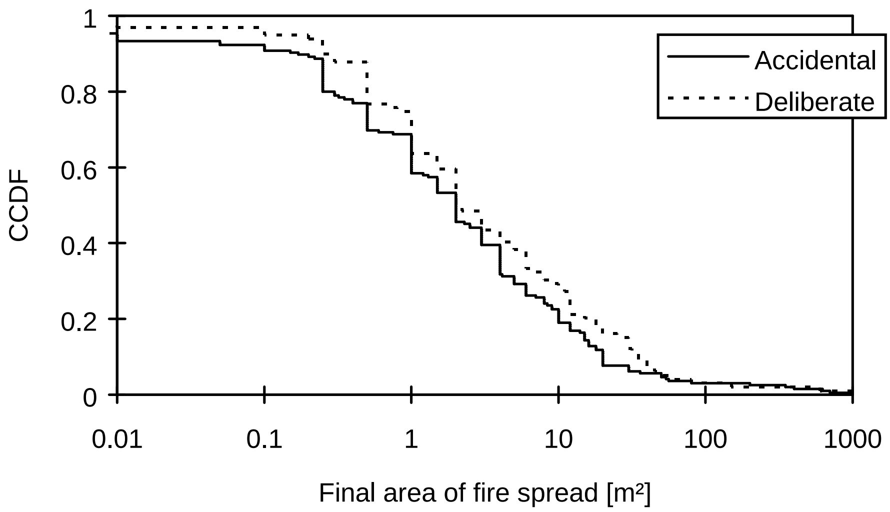


Figure 17. The size of the accidental and the deliberate fires seems to have the same basic type of distribution, but the deliberate ones tend to be larger.

4.2 Causes of ignition

The defect, act or omission leading to fire is normally referred to as the cause of the fire or the cause of ignition. In the present material, the three most common causes of ignition comprise nearly half of the 307 fires. The ten most frequent causes represent two-thirds of the fires. The *deliberate application of naked flame*, e.g. through someone's deliberately setting a fire, is the most frequent of all ignition sources, as shown in Figure 18. Being the cause at 76 of the 307 cases, or 25% of these, it is twice as common as any other source. It is followed by *careless disposal*, such as throwing cigarette butts in paper bins, involving 39 fires or 13% of the fires and by *fault/defect within the appliance*, such as a TV set starting to smoulder while in operation, this involving 32 or 10% of the fires. Each of the other sources is in the order of maximally ten fires each, that is less than 4% of the cases.

All the causes (defined as the defect, act or omission leading to fire) of ignition found in the material are listed in Table 2. The actual number is 42 of the 105 possible causes as defined in the database. In the present material, for example there were no chimney fires, suicides or vehicle crashes which led to fire.

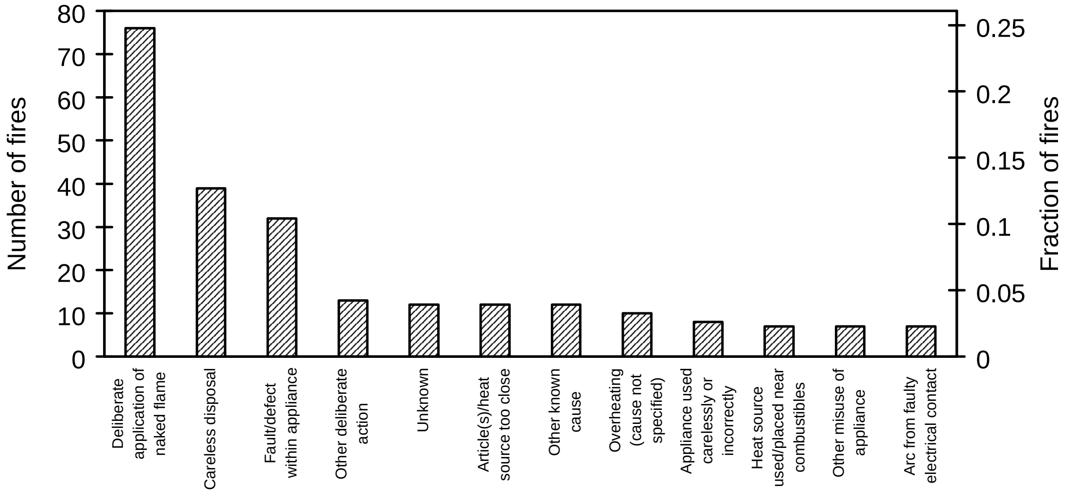


Figure 18. The ten most commonly specified causes (defect, act or omission) of fire.

Table 2. The causes (defect, act or omission leading to fire) of the fires that were investigated.

Code	Description	No	Fract
001	Unknown	12	0.039
034	Faulty power supply in building	2	0.007
037	Leak from gas supply system	1	0.003
041	Faulty lead to appliance	2	0.007
111	Defect causing sparks from vehicle defect	1	0.003
113	Fault/defect within appliance	32	0.104
114	Mechanical heat/ spark, appliance defect	3	0.010
121	Lack of maintenance or worn out	5	0.016
135	Arc from faulty electrical contact	7	0.023
141	Other appliance fault/defect	6	0.020
210	Chip pan left unattended	5	0.016
220	Chip pan ignited while attended	1	0.003
311	Power supply un-intentionally turned on	1	0.003
312	Power supply left on	3	0.010
321	Appliance used care-lessly or incorrectly	8	0.026
341	Spillage or splashing of flammable liquid	2	0.007
351	Penetration of cable by misuse	3	0.010
362	Sparks arising from misuse of appliance	1	0.003
370	Article(s) fell onto heat source	3	0.010
371	Heat source fell on articles	3	0.010
373	Fire or heat source dropped on articles	1	0.003
391	Other misuse of appliance	7	0.023
413	Playing with fire	3	0.010
421	Careless handling of heat,unconsciousness	1	0.003
431	Careless handling of heat - other cause	4	0.013
433	Careless disposal	39	0.127
434	Careless disposal of match	3	0.010
436	Lighted material lit flammable vapour/ liquid	1	0.003
437	Lighted material ignited flammable material	2	0.007
451	Article(s)/heat source too close	12	0.039
711	Heat source used/ placed near com-bustibles	7	0.023
721	Accumulation of flammable material	4	0.013
771	Burning embers blown by wind (from primary fire)	1	0.003
821	Self heating due to incomplete drying	1	0.003
823	Self heating due to contamination by oils paints etc.	3	0.010
826	Thermal degradation	2	0.007
852	Overheating (cause not specified)	10	0.032
971	Item left to cause fire later	2	0.007
981	Item put through letter box	2	0.007
982	Deliberate application of naked flame	76	0.248
991	Other deliberate action	13	0.042
993	Other known cause	12	0.039
	Total	307	1.002

5 Discovery

5.1 Means of discovery

The means of discovery was noted for most of the 307 fires. The seeing of smoke (79 or 26% of the fires) or the smelling of it (69 or 22% of the fires) is the most common way of discovering a fire, found in nearly half of the cases. The seeing of flames or of fire was the initial means of discovering the fire in 52 or 17% of the cases.

There is no information in the data regarding either who alarmed the fire brigade or of the time that elapsed until the fire brigade was called.

In 59 or 19% of the fires, it was an automatic fire alarm and in one case a security system was that first in detecting the fire. In the database, the term *discovery* is used when it is a person who discovers a fire and *detection* when the fire is detected by an automatic system.

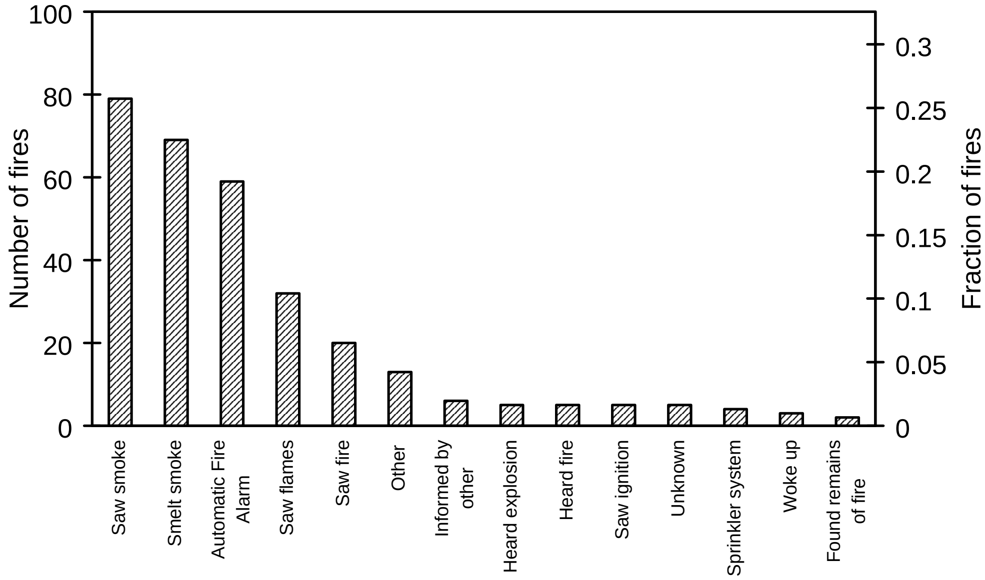


Figure 19. The means of discovery of the fires that were analysed, showing that the seeing or smelling of smoke is the most common way of discovering a fire.

5.2 Automatic fire alarm

In the database there were 82 or 27% of the 307 fires in which there was an automatic fire detection system installed in the premises.

The automatic fire alarms worked properly in only 66 of the 82 fires, or 80% of them. For 13 or 16% of the fires, the system failed to detect the fire, and in 3 cases the fire was detected but the alarm did not sound. The overall failure rate is thus as high as 20%.

Note the difference between the 66 fires in which the alarm worked properly and the 59 fires, referred to in the previous chapter, in which the automatic fire alarm was the initial means of detection. The difference is due to those cases in which someone discovered the fire before it was detected by a technical system.

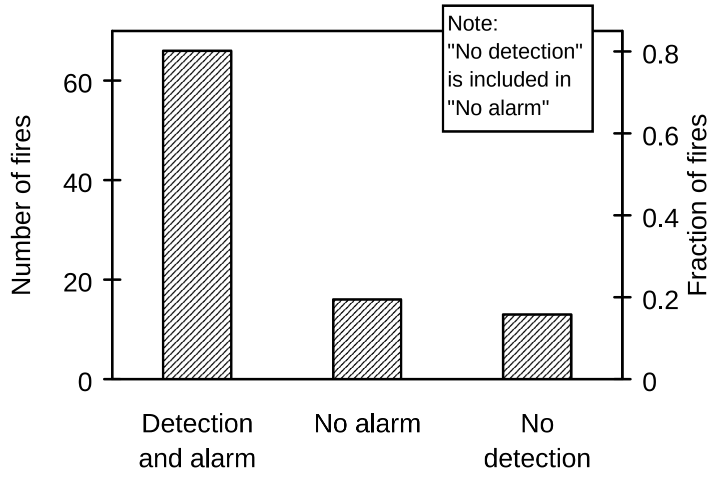


Figure 20. The activation and sounding of automatic fire alarms.

In 16% of the fires, the automatic fire alarm did not activate properly and in 20% of the fires it did not lead to the sounding of the alarm. The different types of causes of failure contained in the database and the number of cases involved are shown in Table 3. Although the number of cases here is small, the functioning of the automatic fire alarm was not always checked on. Nevertheless, both the failure of equipment and management failures clearly occurred.

Table 3. Reasons for failure of the automatic fire detection system.

Code	Type of failure	Number
2	Faulty equipment	4
6	System turned off	1
7	Power supply failed	1
9	Other, not specified	4
-	Not recorded	3

Since the type of premises is known in the case of each fire, it was be of interest to see whether it affected the failure rate. The data for those types of premises for which there were more than five fires involving an automatic fire alarm, are plotted in Figure 21. Despite the number being so low that a single fire can affect the result, the various types of premises seem to be fairly similar in failure rate.

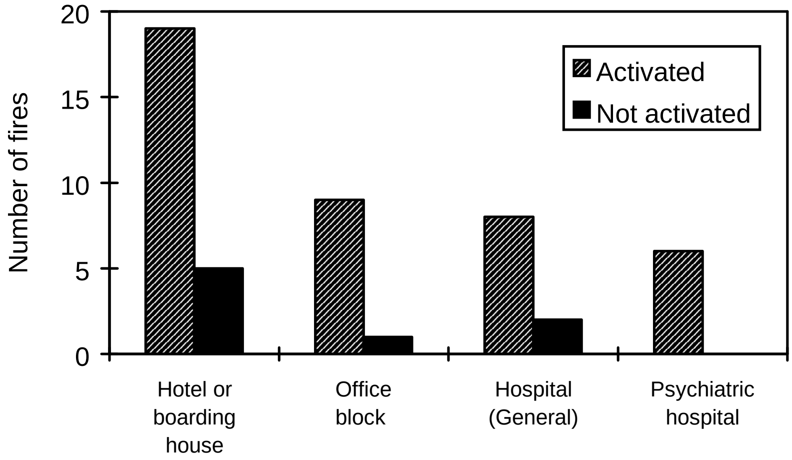


Figure 21. Distribution of failures of the automatic fire alarm on different types of premises.

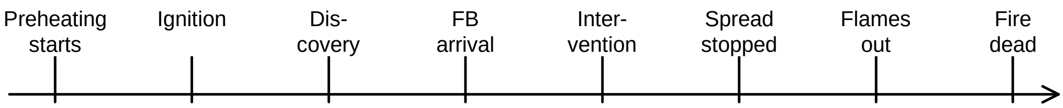
6 Fire growth

The time aspect is often said to be crucial in the event of fire. It is thus worthy of a closer study as a main factor in determining the outcome of the fire. Surprisingly enough, however, there are few studies concerning how the time factor affects the results of the operations launched by the fire brigade.

6.1 Time intervals

The times taken for various events are noted for the fires described in the database. Whenever known, the times taken for the preheating to start, for ignition to occur, for the fire to be discovered or detected, for the fire brigade to arrive, for intervention or ”water on the fire”, for the spread of fire to be stopped, for the flames to go out, and finally, for the fire to be dead are noted.

In the following, a time scale is used to illustrate the logical relations between these different times.

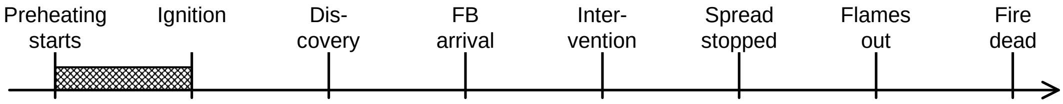


Not all these times appear in every fire. It is not always possible, for example, to determine the time when preheating starts or the time for ignition to occur. Each time interval that was available is included.

The size of the fire is measured in terms of the horizontal floor area (in m^2) involved. Measurements of the size of the fire are available at three separate times: at discovery of the fire, at the arrival of the fire brigade, and at the time when spread of the fire is stopped. The area at which the spread of fire is stopped is equal to the final area of fire spread and is thus a measure of the total area burned by the fire. This area is used to plot the different time intervals against. The area of the fire at ignition is also known, since it by definition is equal to zero.

The fraction of the room of origin burned is calculated by dividing the final area of the fire spread by the product of the length and width of the room.

Preheating - Ignition



The first time interval is from when preheat starts up to the point of ignition. This time period is only known in a comparatively small number of cases, in 50 of the 307 fires. As shown in Figure 22, this parameter seems to have a weak correlation with the final area of fire spread. The correlation between this time period and the fraction of the room of origin which is burned is also weak. However, there appears to be a tendency for fires with a long period of preheating to result in only a small fraction of the room of origin burned.

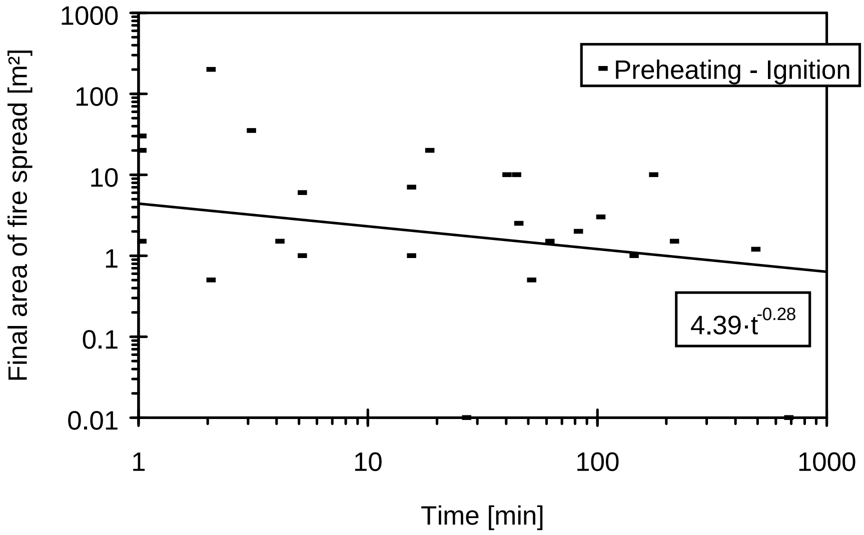


Figure 22. There appears to be a weak correlation between the preheating time and the final area of fire spread. Note that information is only available for 50 of the 307 fires.

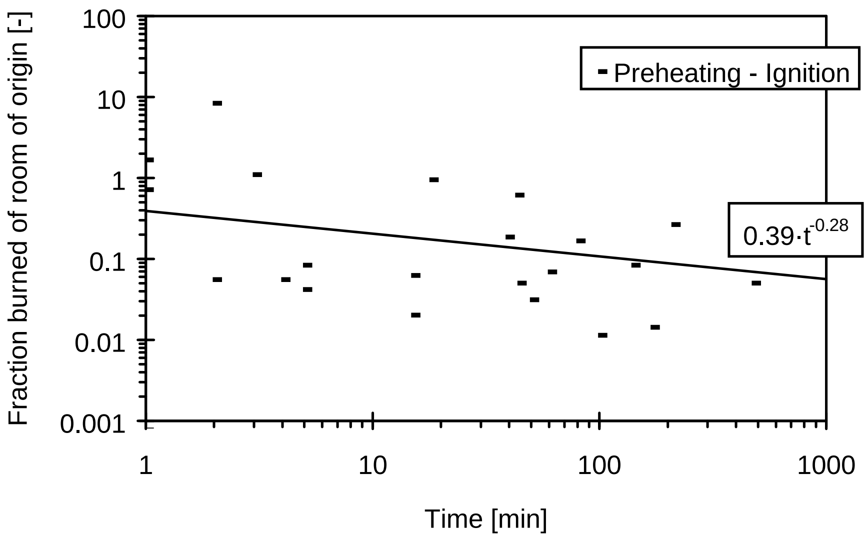
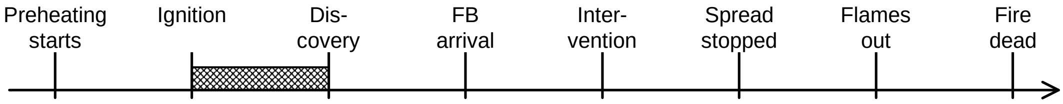


Figure 23. There is a tendency for fires with a long preheating time to remain small, yet the correlation is weak. Note the small sample.

Ignition - Discovery



The time from ignition to discovery is sometimes said to be crucial and to explain why some fires grow to be large. As can be seen in Figure 24, however, the data does not support this. The pattern here seems rather to be a totally random one. There are large fires with a very short time for detection, and there are others having quite long times. However, the present sample is limited, particularly since the time to detection is known for only 116 of the 307 fires.

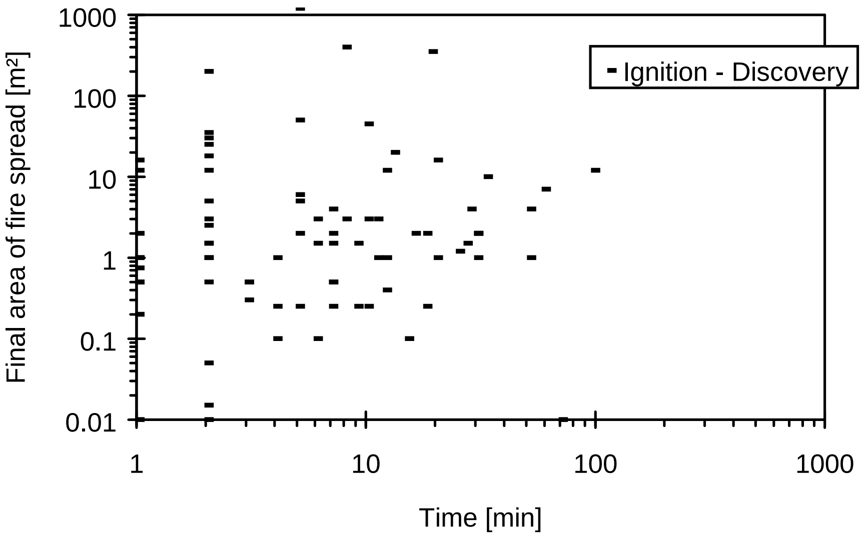


Figure 24. There appears to not be any correlation between the time from ignition to discovery and the final area of the fire.

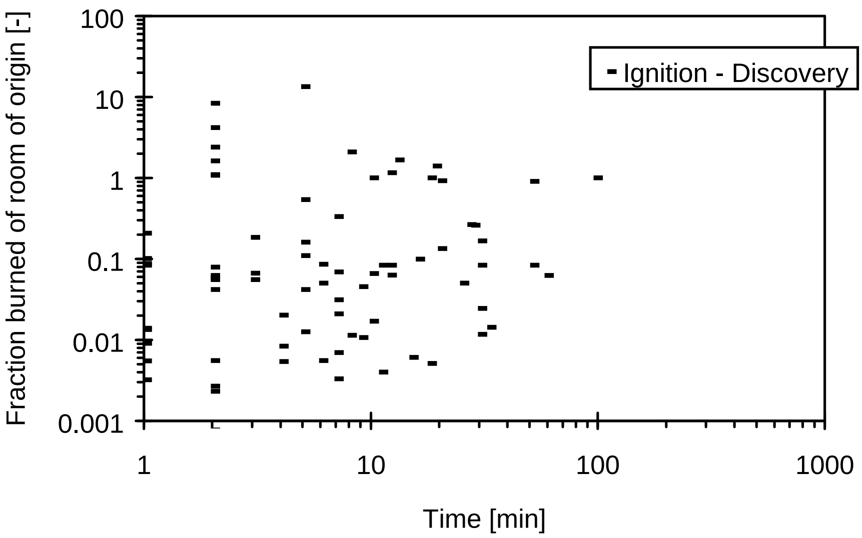
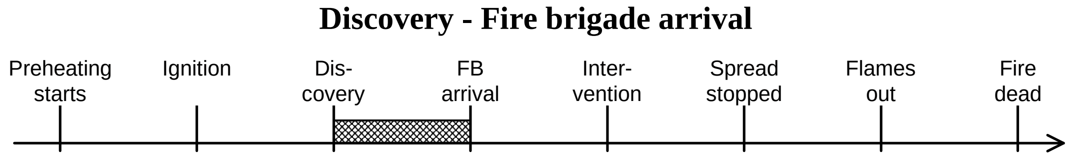


Figure 25. There appears to not be any correlation between the time from ignition to discovery and the fraction of the room where the fire originated which is burned.



The time from discovery of the fire to arrival of the fire brigade is the next time interval available in the database, known for 271 of the 307 fires. It includes the decision time, the time to sound the alarm, the alarm-handling time, and the stand-by and travel time for the fire brigade. The call time itself is not stated explicitly in the database. The time interval from discovery to arrival is generally in the order of 5 to 10 minutes. The data seems to not support the hypothesis that a short arrival time results in a small fire.

A small number of the fires have an arrival time of some two hours. This is not due to a lazy alarm operator or a lazy fire brigade. The reason for this occurring is simply that of the first who discovered the fire not recognising it as a fire and thus not bothering to alarm the fire brigade.

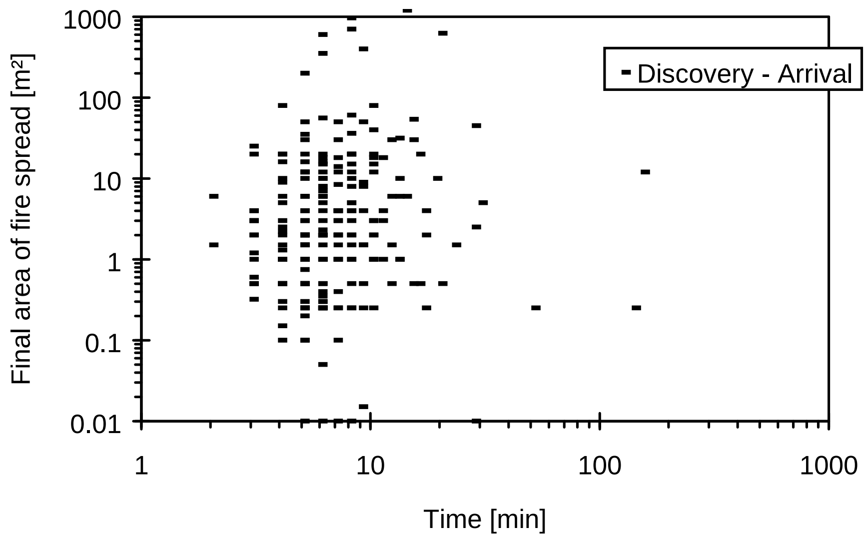


Figure 26. Large fires do not appear to have a short time for arrival. The correlation between is weak.

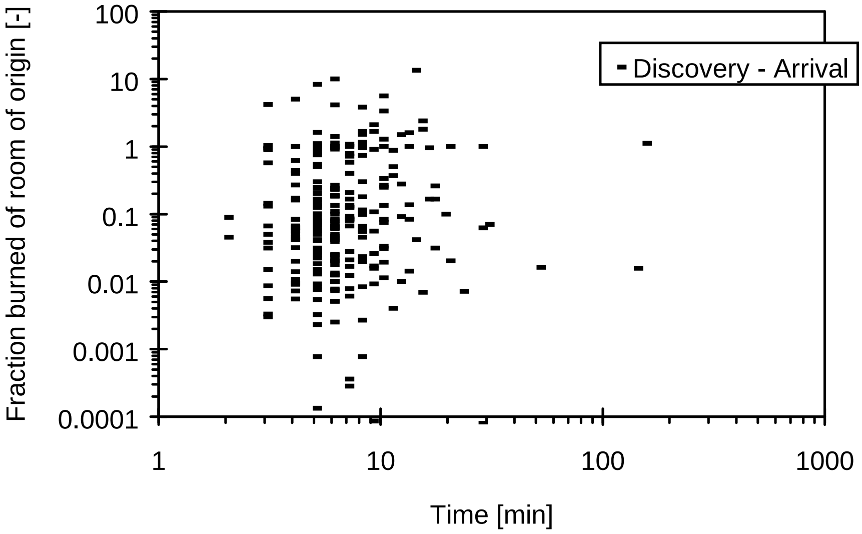
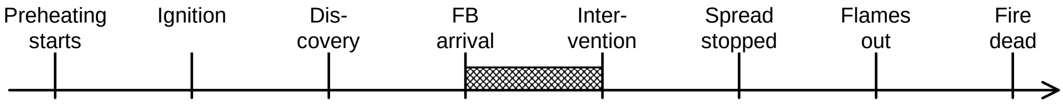


Figure 27. The correlation between the time for arrival and the fraction of the room of origin burned is weak.

Fire brigade arrival - Intervention



The time for the fire brigade to attack the fire is generally short, which comes as no surprise. The longest times to intervention, up to 5 to 10 minutes, are for the small or medium-sized fires. This makes sense since large fires are often obvious and easy to find. Small fires may not be detectable from the outside of a building on arrival at the scene. Even if smoke is present, without a guide, in a complex building or at night, it may be difficult to localise a fire.

The methods employed may also play a role here, every fire brigade having its own standard operation procedures, which certainly affect performance.

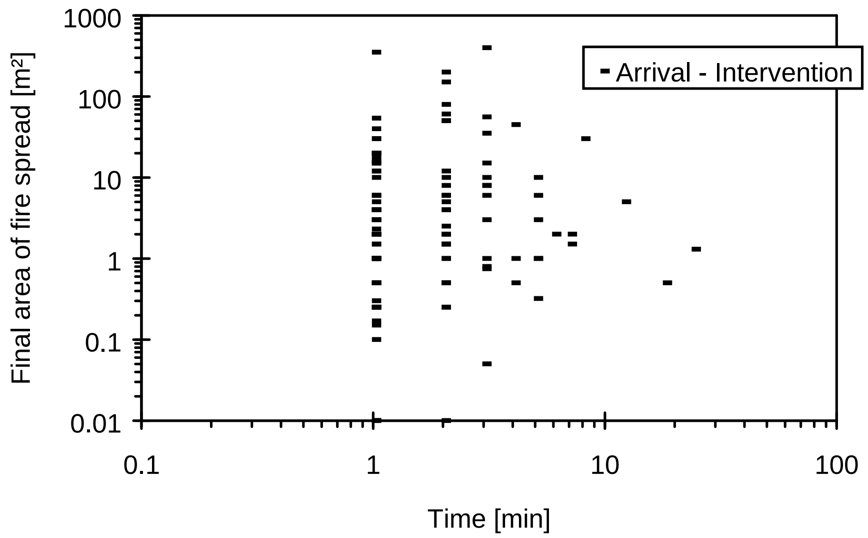


Figure 28. The time from arrival to intervention is usually one to two minutes. The longest times are found for medium-sized fires.

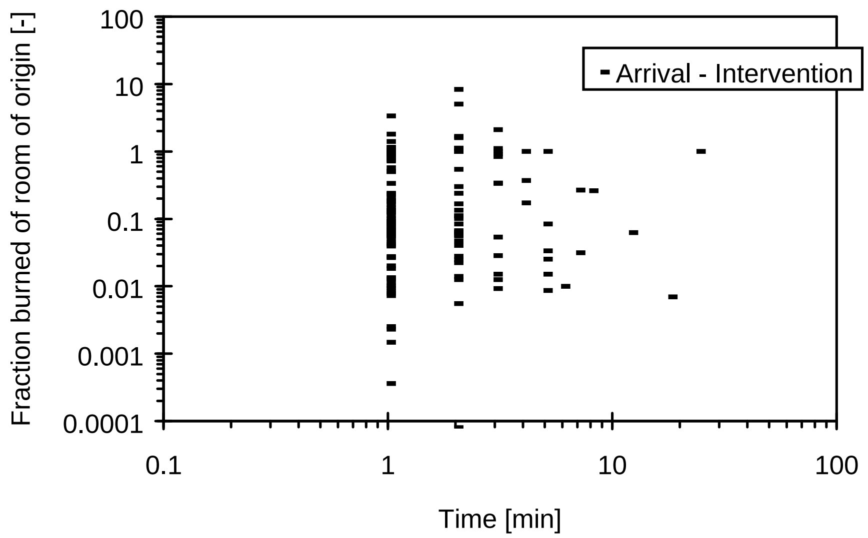
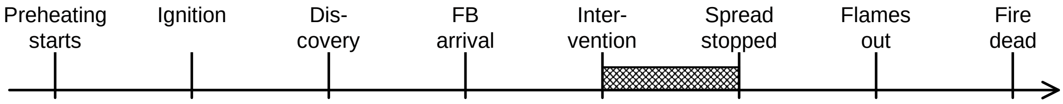


Figure 29. The time between arrival and intervention appears to not be correlated with the fraction of the room burned.

Intervention - Spread stopped



Although the data does not support there being any correlation between the times from when preheating started to the fire brigade intervention, the times following this seem to be correlated. All the time intervals from the fire brigade intervention and onwards show basically the same pattern. The larger a fire is, the longer it takes to fight it. The first interval is the time from intervention to the spread of the fire being stopped, which is known in 152 of the 307 fires. The time increases in almost a linear way with the final area of the fire spread. However, the dispersion of the data is large, giving a factor of 100 for the final area of the fire spread.

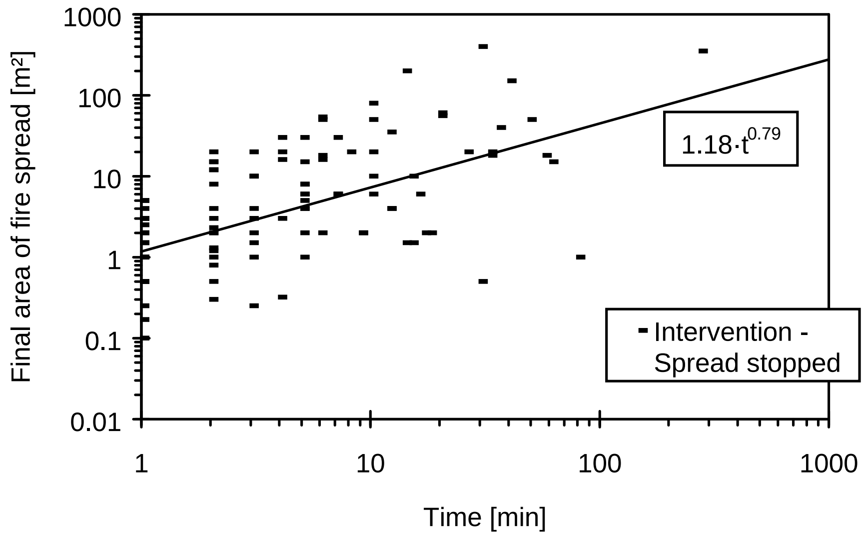


Figure 30. The time from when intervention starts to when the fire spread is stopped is the first time period that is correlated with the final area of fire spread. The larger the fire, the longer time is needed to bring it under control.

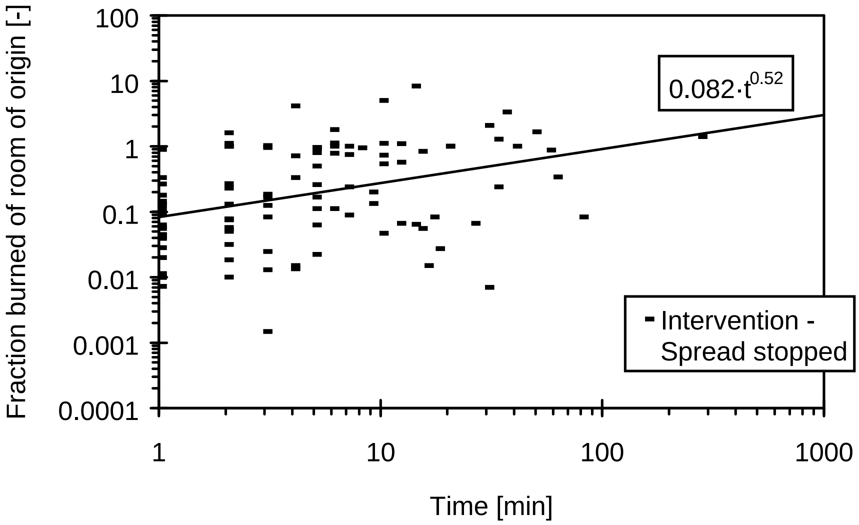
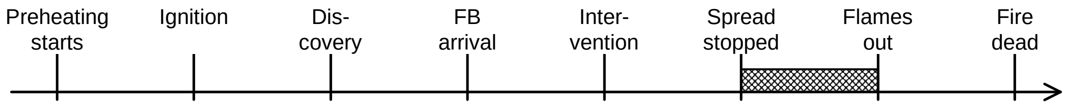


Figure 31. The fraction of the room of origin burned shown as a function of the time from intervention to spread of fire being stopped.

Spread stopped - Flames out



As at the previous time step, the time from the spread of fire being stopped to the flames being out is correlated with the area damaged. It is worthy of note that all fires contained to the room of origin have a time from the spread of fire being stopped to the flames being out of less than forty minutes. This time interval is known for most of the fires, for 238 cases in all.

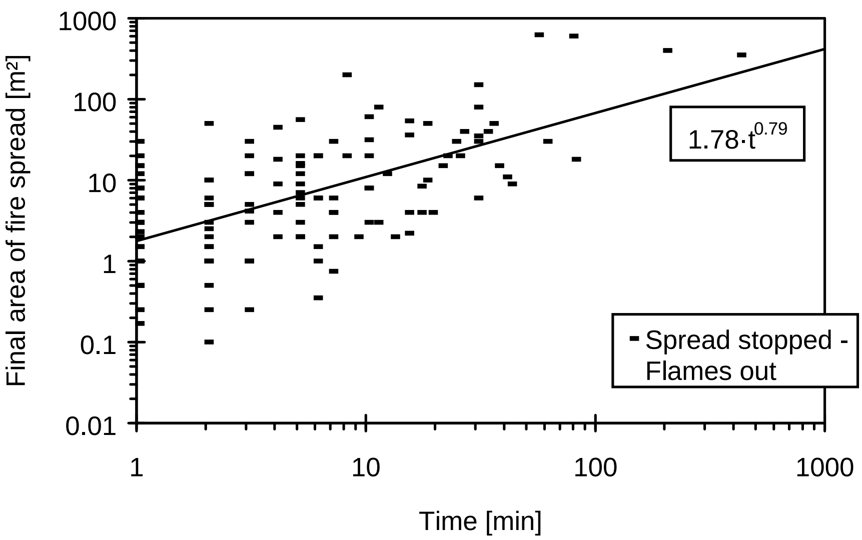


Figure 32. The time from the fire spread being stopped to the fire being out correlates with the final area of the fire.

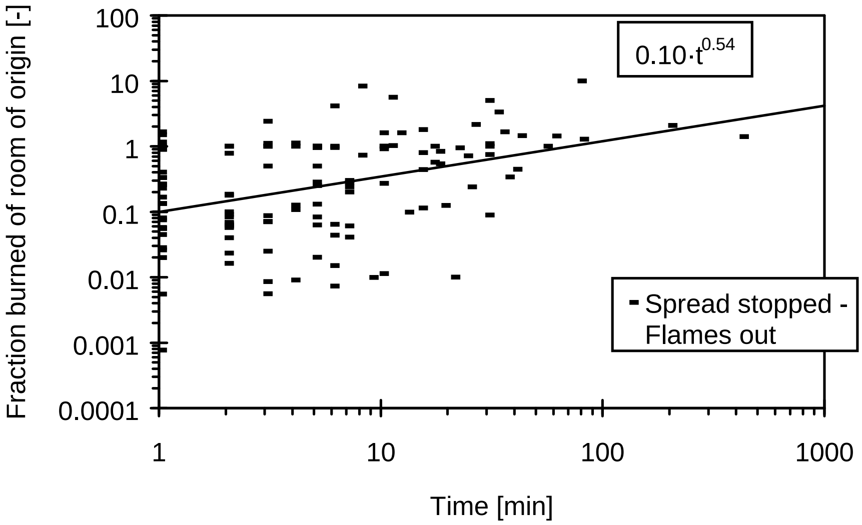
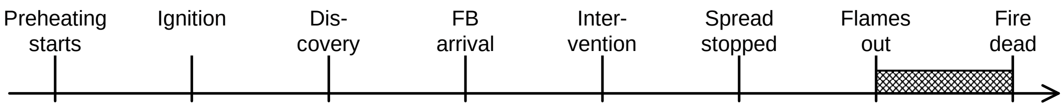


Figure 33. Fires contained within the room of origin have a time from the spread of fire being stopped to the flames being out of less than forty minutes.

Flames out - Fire dead



The last time interval, that from the time until the flames are out until the fire is dead, is known for 236 of the 307 fires. There appears to be a correlation between the two in the material, although the dispersion of the data is large.

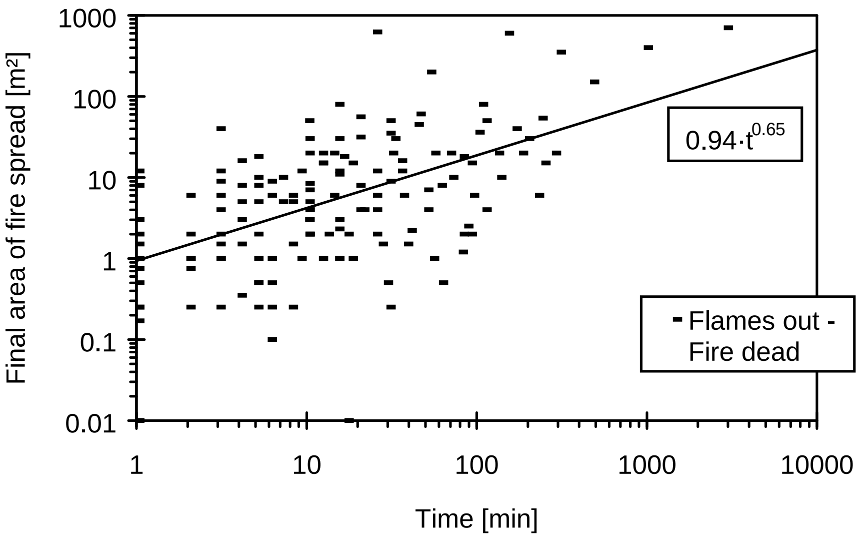


Figure 34. As for the two previous time intervals, the time from flames being out to the fire being dead correlates with the area of the fire.

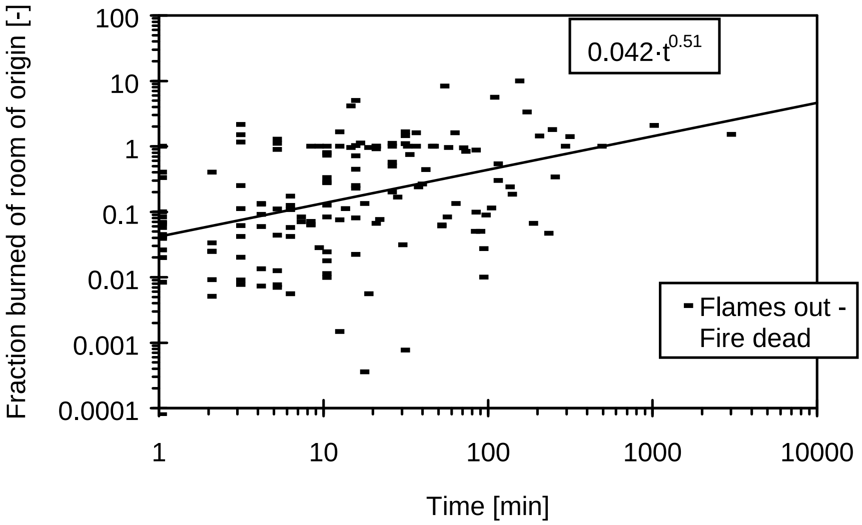
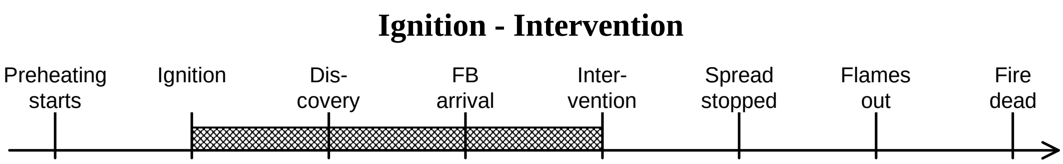


Figure 35. The correlation between the time when the flames are out to the fire is dead and the fraction of the room of origin burned.



The study of the different time intervals during the fire-fighting operation reveals that the time from ignition to fire-fighting does not explain why some fires grow to be larger than others. The explanation in terms of the response time being too long is not supported.

In Figures 36 and 37, the time steps from ignition to intervention are summed. No correlation with the final area of fire spread can be found. Neither can any correlation be found with the fraction of the room of fire origin that is burned. Unfortunately, the number of cases for which both the time for ignition and the time for intervention are known is small.

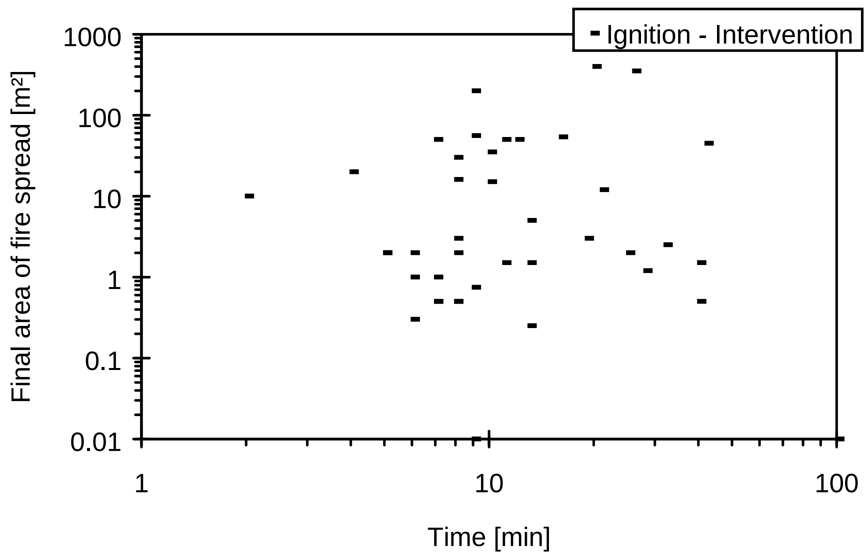


Figure 36. The time from ignition to intervention appears to not explain the size of a fire.

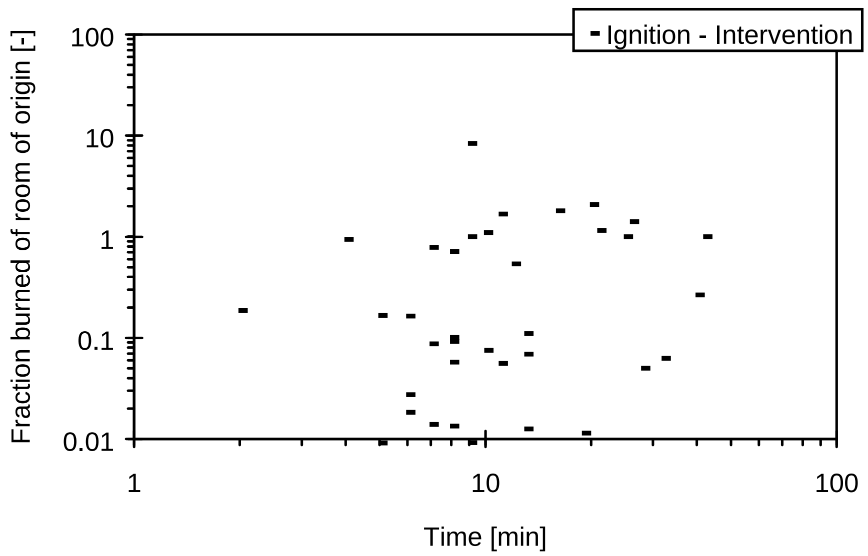
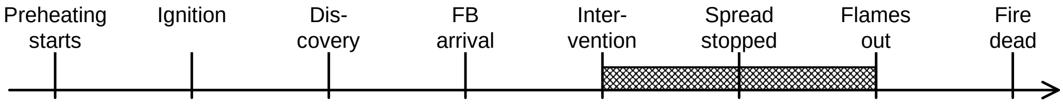


Figure 37. The time from ignition to intervention is not correlated with the fraction of the room of origin burned.

Intervention - Flames out



The entire process of extinguishing the fire is summed in Figures 38 and 39.

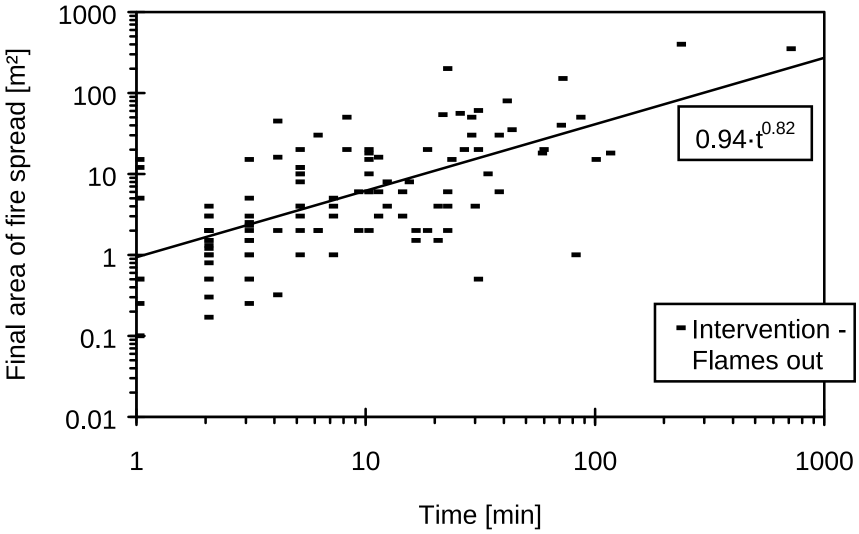


Figure 38. The final area of fire spread is correlated with the time to extinguish the fire

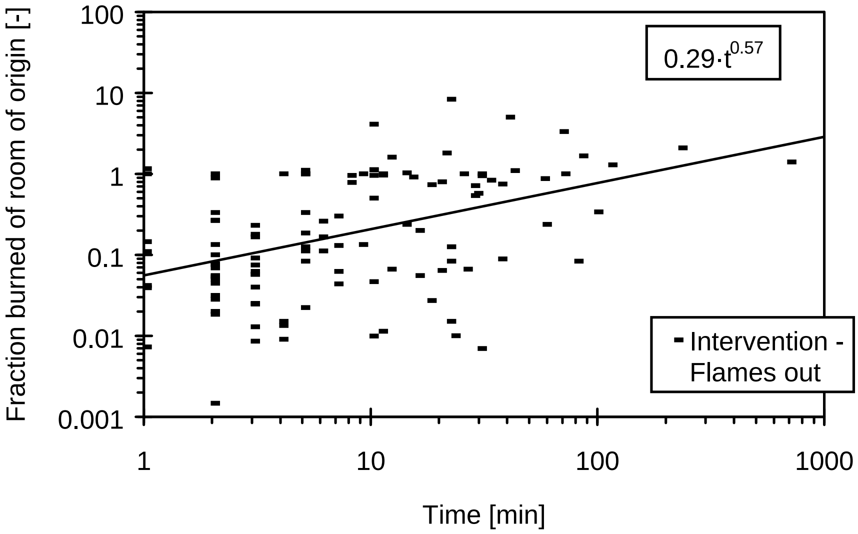


Figure 39. The fraction of the room of origin burned, shown as a function of the time to extinguish the fire.

6.2 Fire area

Contain first, then extinguish is a golden rule for every Incident Commander. However, it seems that in most cases, the fire has already been contained by itself upon the arrival of the fire brigade. Figure 40 shows the relation between the area burned at the arrival of the fire brigade and at discovery to the final area of fire, i.e. the fraction of the fire spread that occurred before either discovery of the fire or arrival of the fire brigade. CCDF stands for the Complementary Cumulative Distribution Function and gives the probability of a fraction occurring that is larger than that indicated on the x-axis. The diagram is based on the 258 fires, of the 307, for which the area at discovery was known. The area at the fire brigade arrival was known for 289 of the fires.

Half of the fires did not spread further after discovery, and three-quarters did not spread after the arrival of the fire brigade. Obviously, this is not due to any fire-fighting operation but rather to the construction of the building and to its contents. Here it is the amount and layout of fuel that is the important factor, rather than the way in which the fire-fighting operation is carried out.

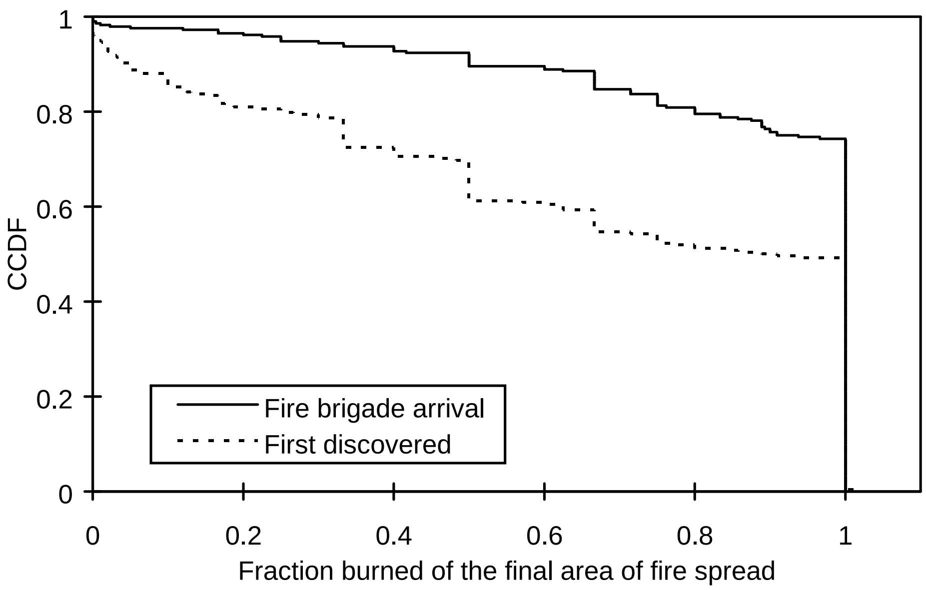


Figure 40. Half of the fires do not grow larger after discovery and three-quarters of the fires do not grow further after arrival of the fire brigade.

In Figure 41, the relation between the area of the fire at discovery and the final area of the fire spread is indicated and in Figure 42 the relation of the latter to the area at arrival of the fire brigade. The lines in the figures represent a twofold and a tenfold increase, respectively, in fire size from discovery to final fire size in the one case and from arrival to final fire size in the other case.

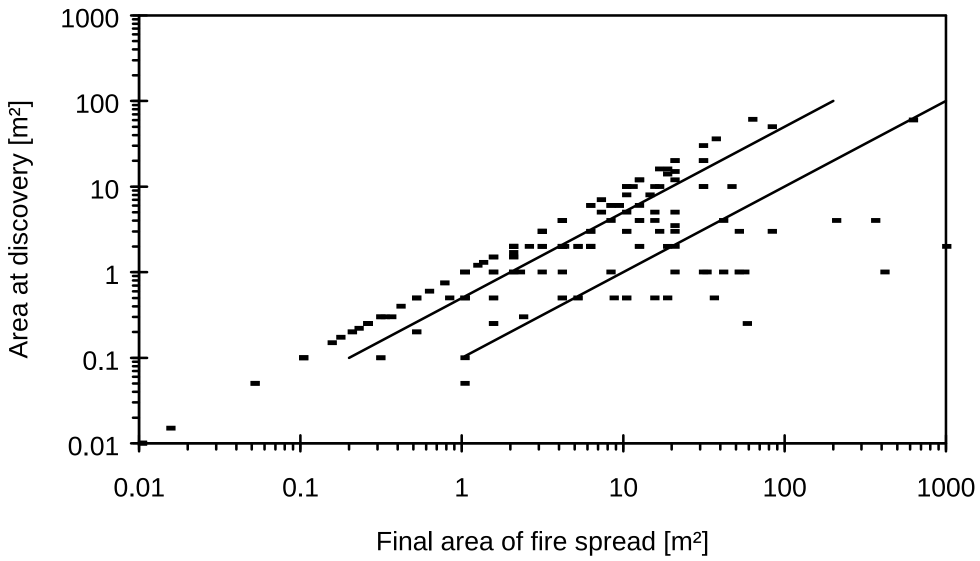


Figure 41. The relation between the area of the fire at discovery and the final area of the fire.

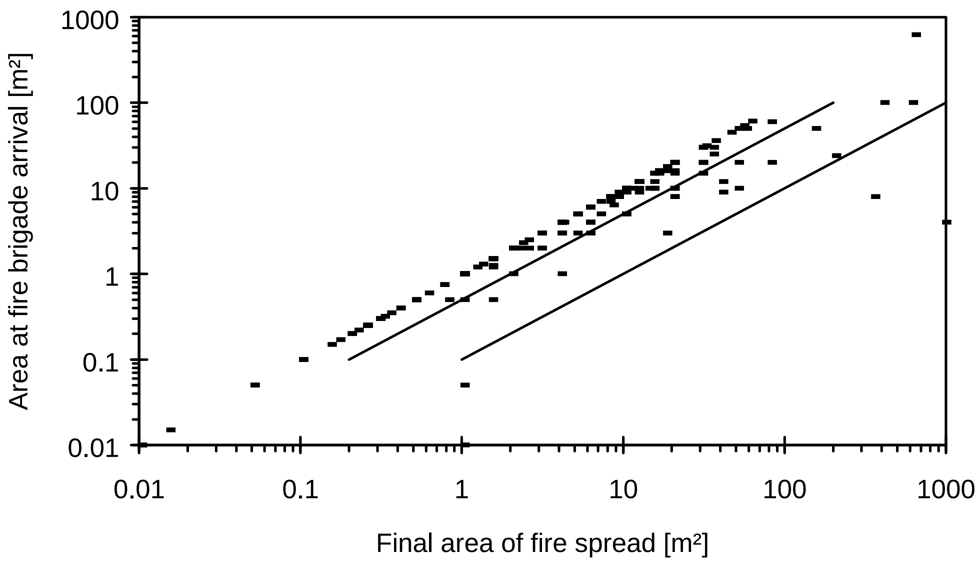


Figure 42. The relation between the area of the fire at arrival of the fire brigade and the final area of the fire.

In the figures, three categories of fire can be identified:

The first type of fire is an incident of the sort in which there is a single, small object that is burning. The incident ends up with a burned area of less than 1 m², the fire in most cases having the same area at the time of discovery as at the arrival of the fire brigade and as the final area of fire spread. This means that the fire has contained itself prior to discovery. Although there is certain possibility of fire spread, a large number of fires of this category can be expected to extinguish themselves due to lack of fuel. For fires of this type, overhaul so as to minimise damage e.g. due to smoke with ventilation, is the most important task for the fire brigade.

The second type of fire has a final size ranging from about 1 m² up to about 40 to 80 m². This category includes the majority of fires. These fires can easily grow by a factor of ten or more after discovery, but are generally contained already at the arrival of the fire brigade. In most cases the change in fire size after the fire brigade arrives remains within a factor of two. The tactical approach is offensive here, commonly involving a fast and aggressive interior attack.

The third type consists of the largest fires, larger than 40 to 80 m². These tend to be larger than 1 m² in size at discovery and 10 m² or more upon arrival of the fire brigade. Here, the fire normally continues to spread even after arrival of the fire brigade. A tenfold fire growth after arrival of the fire brigade is not uncommon. In many cases, the same tactics are used for this type of fire as for the previous one. However, the situation itself is different. The fire is either impossible to reach or has grown so large that it cannot be extinguished by means of an offensive strategy alone. The strategy should best involve an initial defensive operation to secure the boundaries of the fire and then an offensive attack to extinguish it.

In Figures 43 and 44, the area upon discovery and upon arrival of the fire brigade is plotted as a function of the fraction of the room of origin that has been burned. Although this increases the dispersion in the material as diagrammed, the correlative relationship present are still evident.

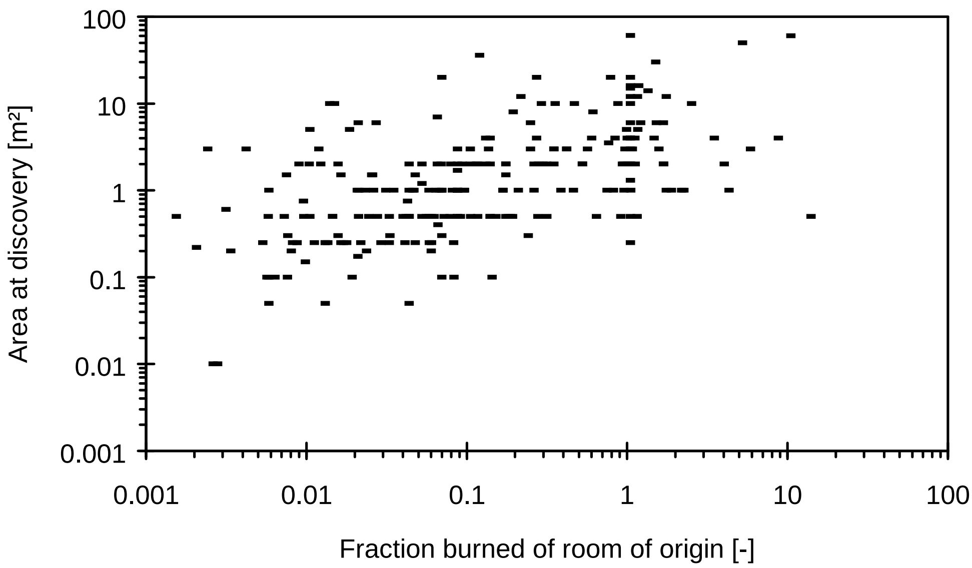


Figure 43. The area at discovery as a function of the fraction of the room of origin burned.

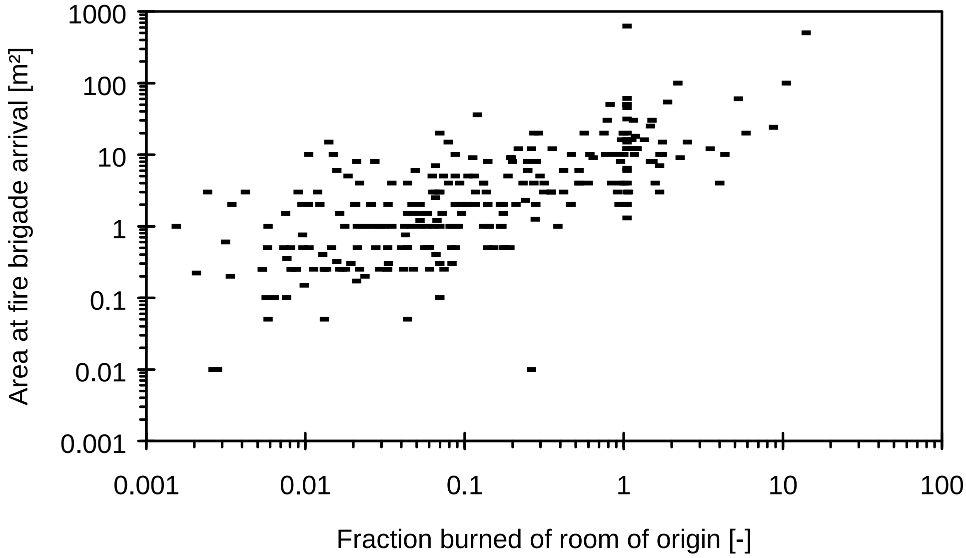


Figure 44. The area of the fire at arrival of the fire brigade as a function of the fraction of room of origin burned.

6.3 Statistical description

Since the parameters described in this chapter can be used in different types of engineering relations, they are presented here using a Complementary Cumulative Distribution Function, CCDF, together with calculated means and standard deviations. Note that log-linear-scales are used.

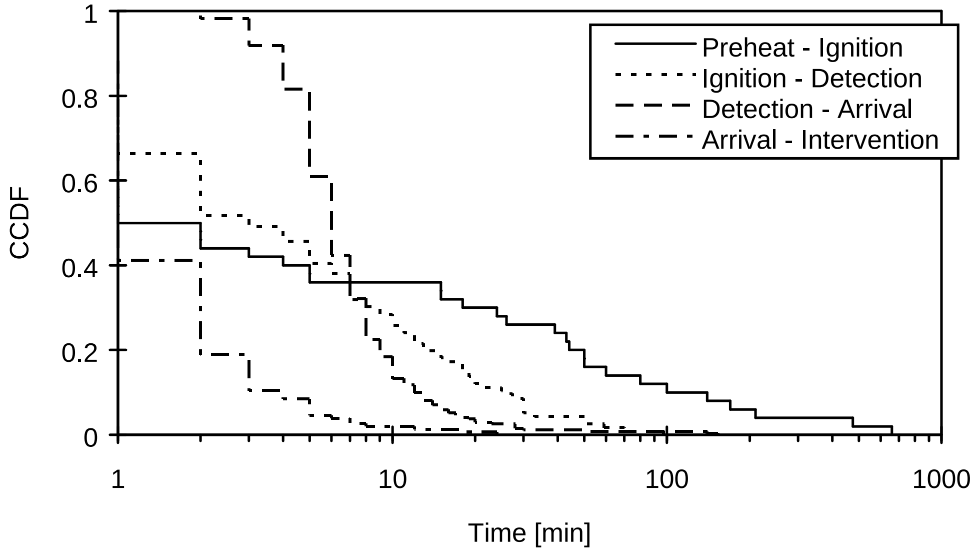


Figure 45. The CCDFs of the different time intervals prior to fire brigade intervention.

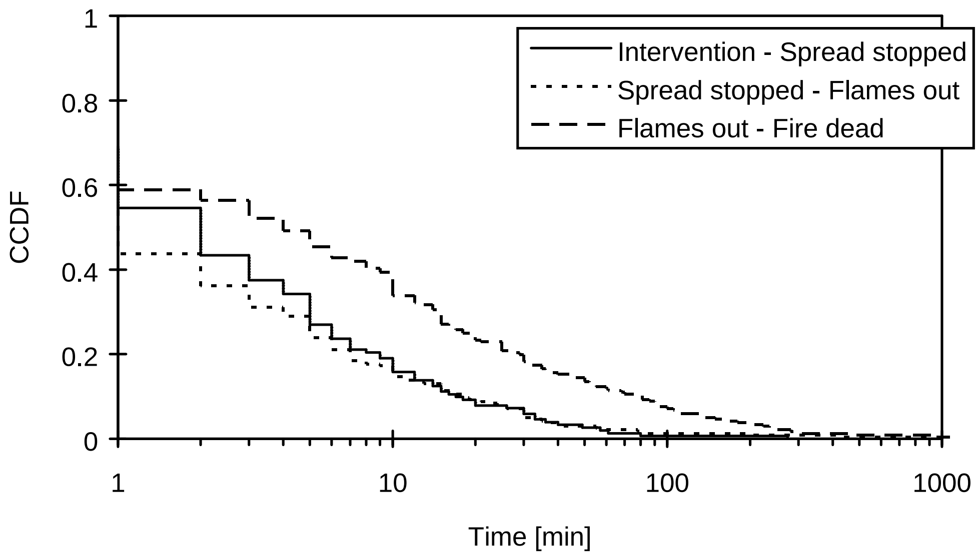


Figure 46. The CCDFs of the different time intervals after fire brigade intervention. The intervals appear to be similar in the type of distribution function involved.

In these figures, all the times available are included. Thus, 50 cases are available for the time from when preheating started on to ignition, whereas 238 cases are available for the time from spread of the fire being stopped to the flames being out. It can be argued that to compare the different distributions, all must have been collected from the same population. For most of the fires, some of the times are missing, most commonly the time to the start of preheating or to ignition. However, in 27 of the 307 fires, all the time intervals are available. In the following figures the distribution functions obtained are compared with those for the 27 fires.

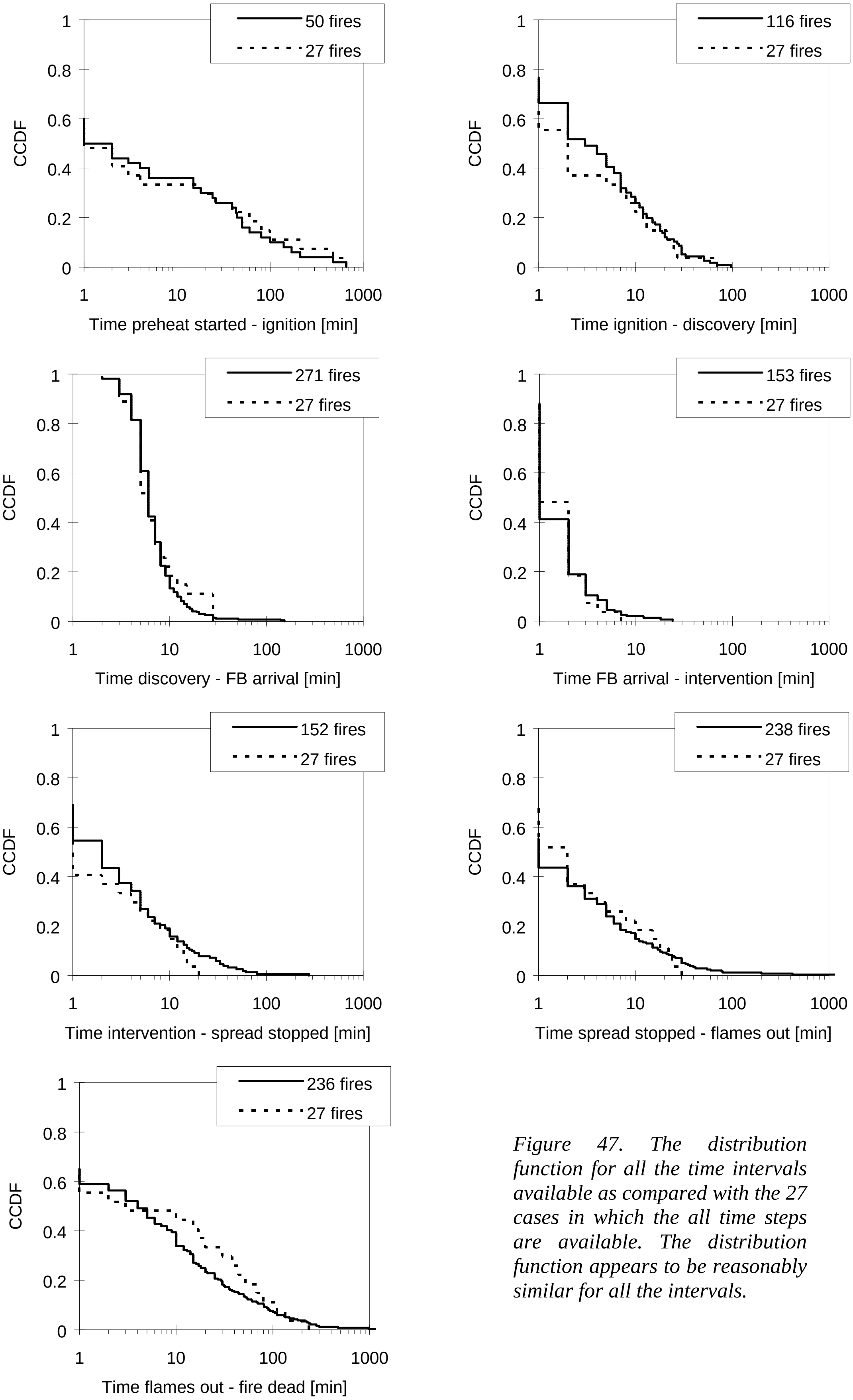


Figure 47. The distribution function for all the time intervals available as compared with the 27 cases in which the all time steps are available. The distribution function appears to be reasonably similar for all the intervals.

The CCDF of the fire area at each of the three different times is shown in Figure 48. The final area of fire spread, together with the area of the fire when the fire brigade arrived and the area when the fire was first discovered are included in the diagram. Note, as was previously shown, that for half of the fires the area is of the same size in each of the three cases.

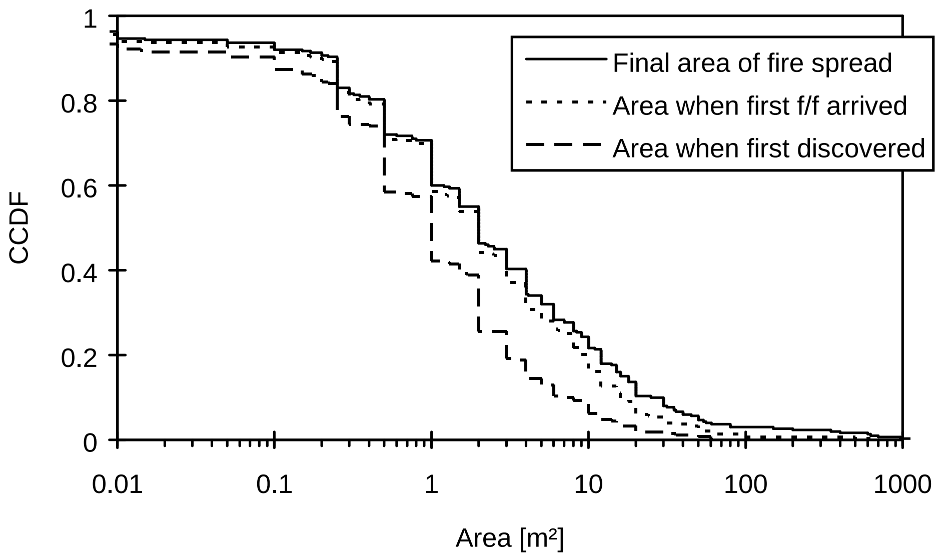


Figure 48. The CCDFs of the area of fire spread at three different times.

Figure 49 shows the CCDF of the fraction of the room of origin that is burned as found at three different times: final state, when the fire brigade arrived and when the fire was first discovered. Note the drop in all three lines when the fraction equals one, i.e. when the fire spreads from the room of origin to the next room.

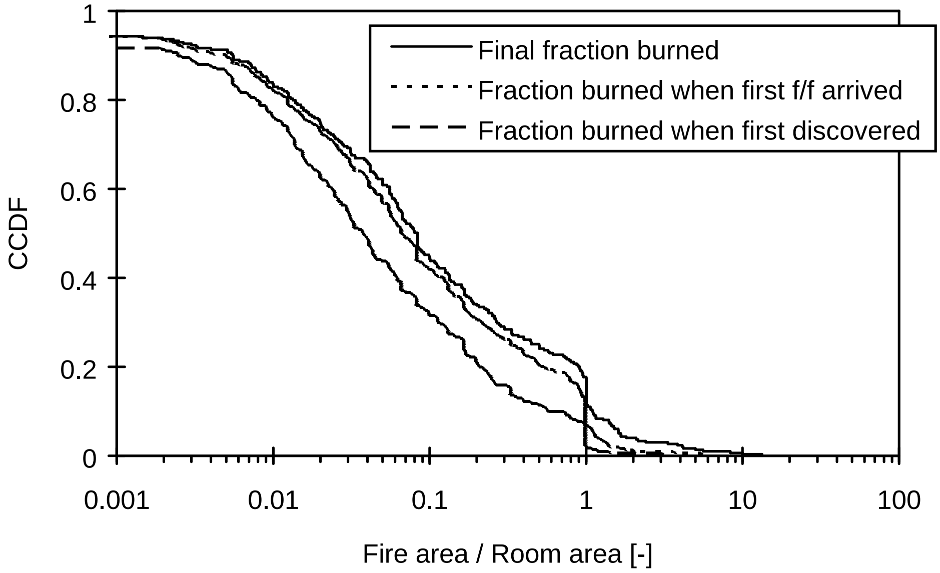


Figure 49. The CCDF of the fraction burned, defined as the relation between the area of fire spread found at three different times and the room area. Note that the lines do not cross each other at 1.

Table 4 gives the mean, standard deviation and number of fires for all time intervals and fire areas in the material. Note the high standard deviation for many of the parameters, reflecting the large dispersion in the material.

Table 4. The mean and standard deviation of the parameters and the number of fires on which they are based.

Parameter	Mean	St. dev.	Cases
Time Preheating - Ignition [min]	44.9	118.3	50
Time Ignition - Discovery [min]	9.1	15.0	116
Time Discovery - Arrival [min]	8.4	13.0	271
Time Arrival - Intervention [min]	2.0	2.8	153
Time Intervention - Spread stopped [min]	7.4	25.1	152
Time Spread stopped - Flames out [min]	13.3	87.8	238
Time Flames out - Fire dead [min]	40.3	203.5	236
Area when first discovered [m²]	3.2	7.3	269
Area when first f/f arrived [m²]	10.0	47.3	299
Final area of fire spread [m²]	24.0	113.4	300

7 Extinction

7.1 Water flow rates

Fire area

The fire area when the extinguishing medium is applied is not specifically given in the database. Three other areas are available, however. The first is the area when the fire was discovered. This area is used in attempts to extinguishing the fire (mainly by use of hand extinguishers) prior to the arrival of the fire brigade. The second, the area at the time the fire brigade arrives, is not considered in this chapter. The last area, the final area of fire spread, is used for the time when the fire brigade attack begins.

Water flow rate

The extinguishing process is described in the database by means of three parameters: the type of extinguisher (i.e. the type of hose or nozzle), the time when the extinguishing medium was applied and the duration of its being applied. Such a description is given for each part of the extinguishing process.

The different attacks are of two types. Attacks that are completed, but are followed by another (stronger) attack, such as failures in attempts to extinguish the fire, are handled separately. Attacks in which the time for fire spread being stopped is during the period of extinguishing the fire are treated as involving use of a sufficient amount of extinguishing agent. This is a simple way to differentiate between mere attempts to extinguish the fire and successful operations.

The extinguishing process is described for at 281 of the 307 fires. There are also 87 cases of unsuccessful attempts that had to be followed by another (stronger) attack.

Table 5. The codes and descriptions as used in the database, together with the corresponding water flow involved [C].

Code	Description as used in the database	Water flow [l/min·nozzle]
34	Water extinguisher	8.0
51	LP hose reel -tank supply	114
52	LP hose reel - augmented supply	114
53	HP hose reel - tank supply	114
54	HP hose reel - augmented supply	114
55	Main branch - Jet	870
56	Main branch - Fog/spray	350
64	Monitor, ground or aerial type	1800
71	Fixed installation (Sprinkler)	70

In order to calculate the water flows, it was assumed that the water flow rate from a nozzle is as shown in Table 5. A normal water extinguisher gives about 8 l/min and the common hose reel about 112 l/min. At phases of the fires in which several nozzles were in operation, the water flows from the various nozzles were added, giving the total flow of extinguishing agent for this phase of the fire. Figure 50 shows the flow rate of the water to be roughly proportional to the square root of the area of the fire.

The water flow rates in the table represent the maximum value when the discharge valve is fully opened. For smaller fires it is not certain that this is the case, an over-estimating of the water flow being possible. It is also assumed that the nozzle pressure is 5 bar. Variations in the flow rate depending on differences in pump pressure or on pressure losses in hoses or other equipment are not taken into account.

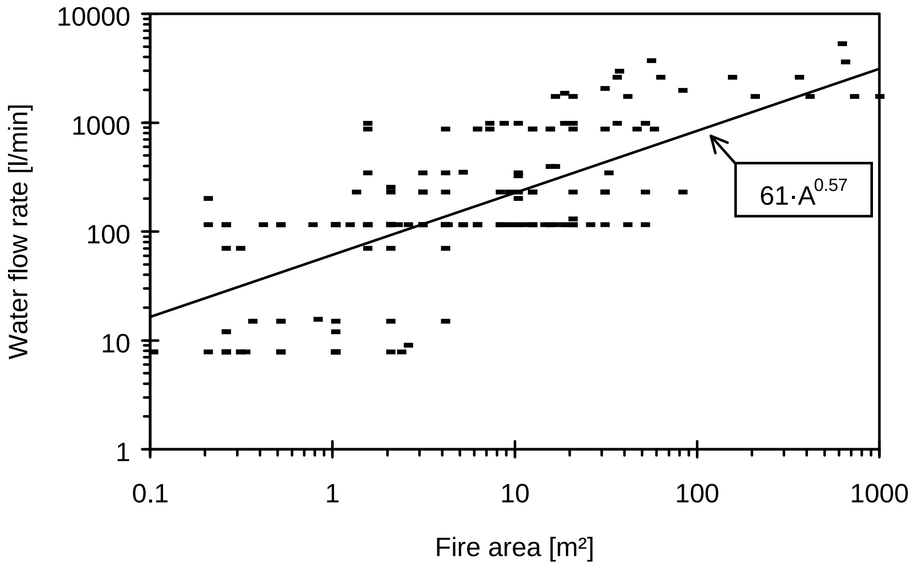


Figure 50. The water flow rate in extinguishing fires.

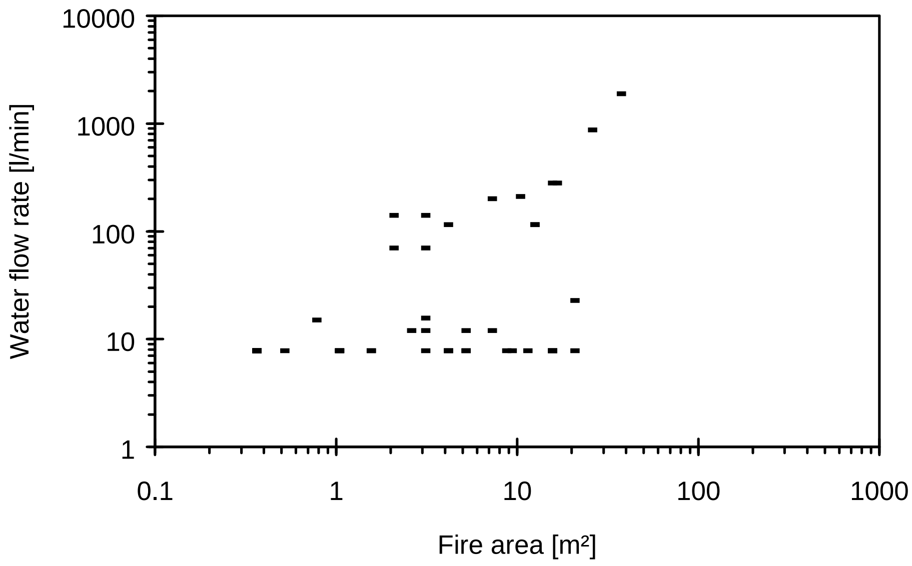


Figure 51. The water flow rate in attempts that had to be followed by another (stronger) extinguishing attack.

Water application time

The duration of each extinguishing phase, sometimes referred to as the control time, is available in the database. The time proves to be proportional to the square root of the area of fire, as given in figure 52. At extinguishing attempts, there appears not to be any correlation between the water application time and the final area of fire spread.

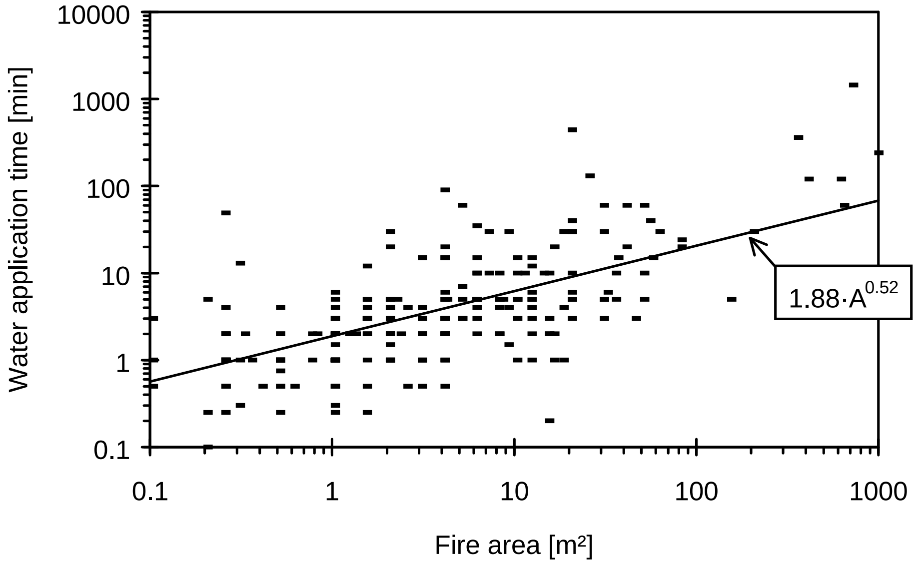


Figure 52. The water application time for fires that were extinguished.

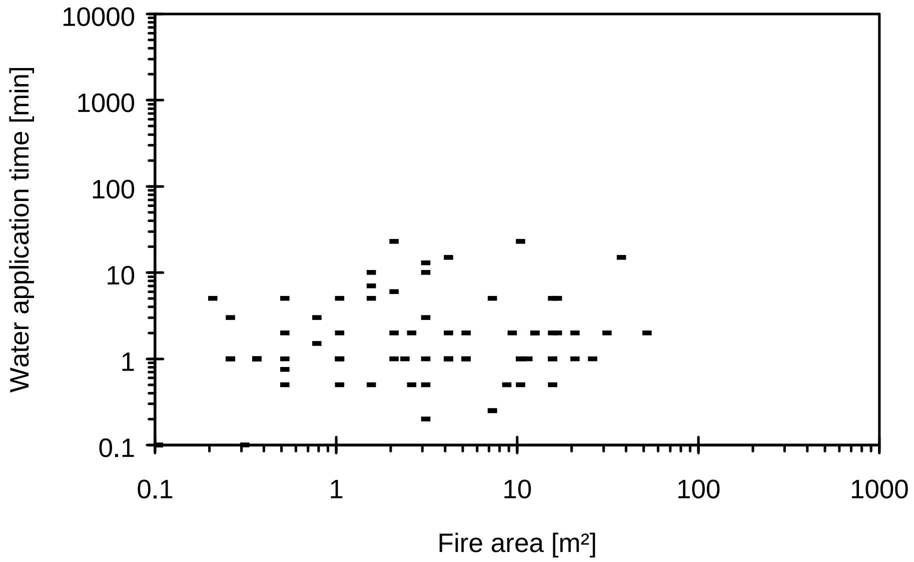


Figure 53. The water application time in attempts that had to be followed by another (stronger) extinguishing attack.

Total water demand

In a previous section, the water flow rate was determined. The flow rate can be used to determine the volume of water that was actually used. The water application time multiplied by the flow rate gives the total amount of water, as given in Figure 54. The total volume of water is shown roughly proportional to the area of the fire, giving a flow rate of about 100 - 200 l/m².

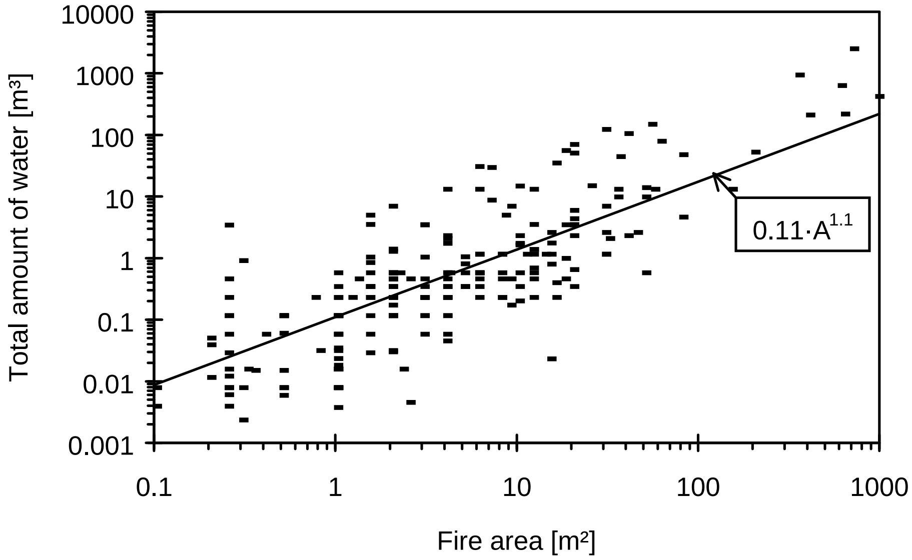


Figure 54. The total amount of water used for fires that were extinguished.

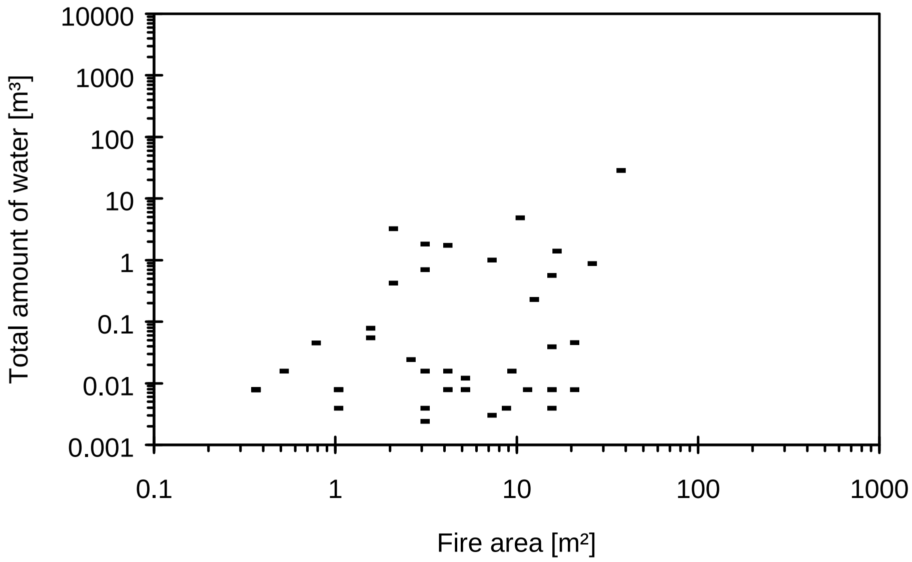


Figure 55. The total amount of water used for fires that required an additional (stronger) attack.

7.2 Attending pumps

Another way of describing the fire-extinguishing process is in terms of the resources needed for the operation rather than of the flow of extinguishing medium. In London, with its 113 fire stations, a lack of resources is not generally any appreciable problem - as long as the fire does not occur during a time of the day when traffic can cause long response times. In none of the fires that were studied was the need of resources greater than those that were achievable.

Due to the British time-weight system, the response forces are highly standardised. A fire station in London normally consists of one or two pumps or pump-ladders. The crew commonly consists of 5 men on each pump. There are few special vehicles. For example, there are only 14 turntable ladders and hydraulic platforms in the brigade. Officers (station officers and above) travel to fires in private cars equipped with lights and a siren.

Figure 56 shows the number of appliances as a function of the final area of the fire. The upper limit of what it is possible to handle seems to be about 50 m² for a two-pump incident and over 100 m² for a four-pump incident. For all operations up to a six-pump fire, the lower limit is less than 1 m². This indicates the size of the fire to only be one of the parameters to be taken into account in determining the required resources.

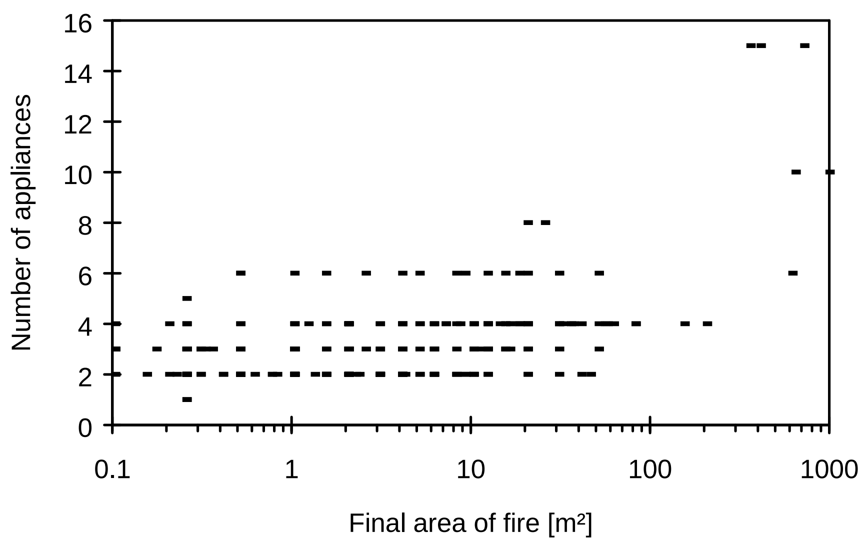


Figure 56. The total number of pumps (appliances) attending in relation to the final area of the fire.

The number of appliances (pumps) used in the relation to the fraction of the room of origin that was burned is shown in Figure 57. In no cases in which the fire was contained in the room of origin were more than six appliances employed.

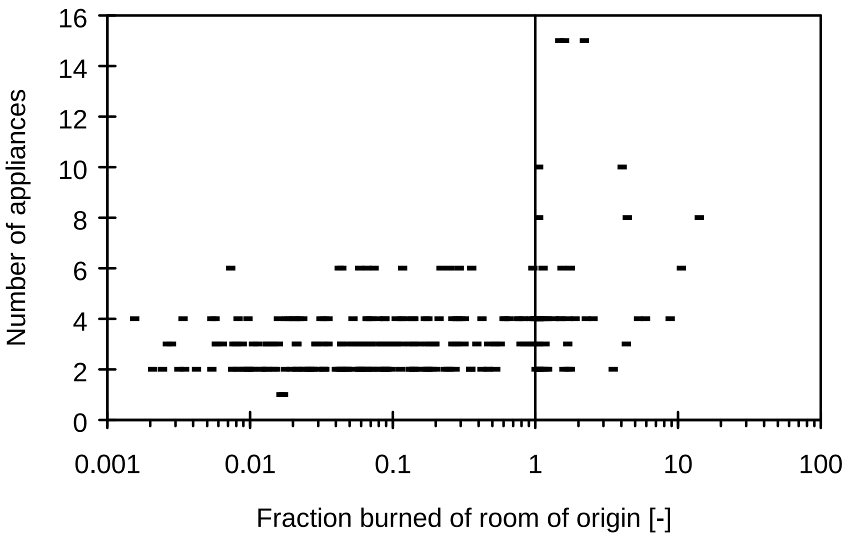


Figure 57. The number of appliances on the scene as a function of the fraction of the room of origin burned.

7.3 Automatic sprinkler

Only 23 of the fires analysed occurred on premises protected by automatic sprinkler systems. Although the number of such cases is small, the performance of the systems generally seems to be satisfactory if the sprinkler system covers the area of the fire and is in order. In 7 cases the fire was extinguished and in 10 cases the sprinkler system contained the fire. In 2 cases, the sprinkler system did not play any appreciable role in the fire.

However, in 4 of the fires the sprinkler system failed to contain the fire. In two of these cases, the sprinkler system did not cover the area of fire (the fire was either above the sprinkler heads or inside a duct), in one case the system having been turned off the day before the fire and in the other case the sprinkler heads was having been manually broken off.

Some of the fires resulted in a large number of the sprinkler heads operating. All of these fires were shown to involve flammable liquids.

Although the number of sprinkler systems studied is small, the conclusion drawn is that a sprinkler system can normally put out a fire using a small number of heads (1-3 of them). This is true for 15 of the 23 fires analysed. Three conditions need to be met, however:

- The system has to be in order. If the system has been manipulated or shut off, it will certainly not function properly. This was the case in 2 of the fires.
- The system has to cover the fire area. If the fire is above the sprinkler heads, in a duct or in another part of the building, it is not of much use. This was the case in 3 of the fires.

- Since the presence of flammable liquids will lead to a fire which is larger than a fire in a ”one head area” would be, a large number of heads needs to operate then, as was the case in the remaining 3 fires.

It is worthy of note that the number of fires investigated that involved sprinkler systems is small, due to the fact that automatic sprinkler systems are traditionally not particularly common in Britain. Thus, the failure rate cannot be determined with any high degree of confidence. The data seems to support the general idea, however, that most fires can be put out by use of only a small number of sprinkler heads, often only one.

In most of the fires, it was noted how many sprinkler heads were operating. More than half of the fires, 10 of 17, were controlled or extinguished with only one head operating, as shown in Figure 58. In fact, 15 of 17 fires were controlled or extinguished with four heads or less.

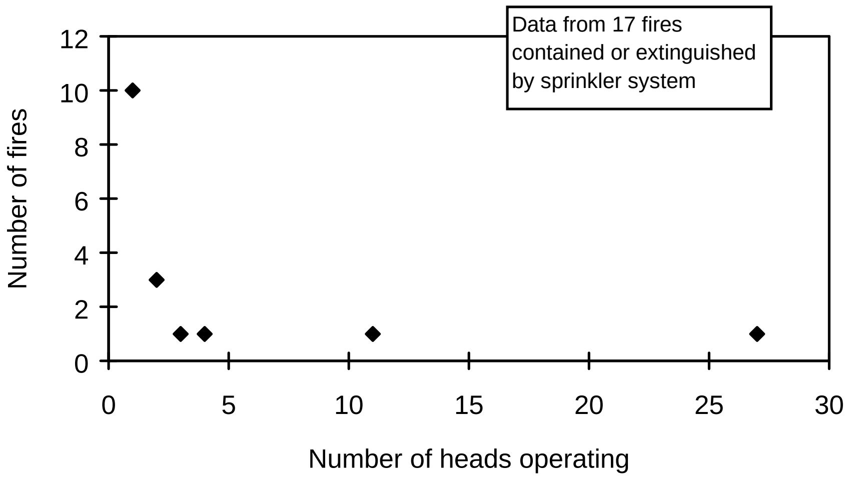


Figure 58. Number of heads operating in fires contained or extinguished by the sprinkler system.

A very interesting finding is that all the fires in which the system was functioning properly and which operated more than three heads involved flammable hydrocarbons: ethylene glycol monomethyl ether (27 heads), hydrocarbon (naphtha) solvent (11), or thinner and lacquer vapour (4). None of the other fires involved flammable liquids. Instead they involved solid materials, commonly having a non-melting behaviour in case of fire.

8 General discussion

The information collected by the Fire Investigation Units of the London Fire Brigade proves to be of great value in understanding the relation between fire development and fire-fighting actions, and in starting to quantify fire-fighting operations. The database would be of even greater value if additional parameters were included. Examples of parameters not yet included are estimates of the area damaged due to smoke and that due to water, estimates of the direct and indirect damage as expressed in economic terms, and fire compartmentation (rather than number of floors involved in the fire). At present, the development of fire is not yet quantified. The perhaps most important task for improving the database is to describe the amount and configuration of the fuel and the room layout, in such a way that the development of a fire can be quantified.

A problem in describing fires, especially if the same approach is to be used in the case of small incidents as of huge fires, is to quantify the events and actions involved, so that fires can be compared statistically.

The database was not fully investigated in this study. Two large areas that the present report does not cover are matters of residential or domestic fires and the problems concerned with the evacuation and search and rescue process. There are further parameters to be studied. The number of fires contained in the database is growing constantly. As the size of the database increases, so does the statistical confidence one can place in the material.

No comparison with other countries has been made in this report. This is certainly a matter worthy of closer study: Are the data and the conclusions drawn in this report valid for other countries and for other cities as well?

9 Acknowledgements

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BRANDFORSK
Styrelsen för svensk brandforskning

Figure 59. The project was carried out together with the London Fire Brigade (left) and with South Bank University, London (right). It was funded by BRANDFORSK, The Swedish Fire Research Board.

10 References

A. London Fire and Civil Defence Authority, London Fire Brigade, *Fire Investigation*, Operational Note 102 (Rev 1), 22 may 1997.

B. London Fire and Civil Defence Authority, London Fire Brigade, *Fire Investigation - procedures and protocols*, Operational Note 272, 22 July 1996.

C. London Fire Brigade, *SRDB Code No. 4, 8 and 13*. (Water flow rates from different nozzles)