Effectiveness of Fire Safety Components and Systems

I.R. THOMAS*

Centre for Environmental Safety and Risk Engineering, Victoria University of Technology, PO Box 14428, Melbourne City MC, Victoria 8001, Australia

ABSTRACT: A concept of fire safety system effectiveness incorporating two elements, efficacy and reliability, is introduced. Historical USA fire data is used to estimate the levels of effectiveness of several fire safety systems in terms of extent of flame spread, the rates of firefighter injuries and civilian fatalities and injuries, and estimated $ loss in fires reported to fire brigades. Based on the data analyzed, sprinklers appear to have greater effectiveness than detectors and protected construction for reducing extent of flame spread and generally (but not always) for reducing the rate of firefighter injuries, civilian fatalities and the estimated $ loss per fire.

KEY WORDS: fire safety, reliability, effectiveness, fire spread, sprinklers, detectors, protected construction.

INTRODUCTION

IN ENGINEERING DESIGN, it is usually assumed that incorporated components and systems operate or act beneficially as envisaged by the designer and do not have detrimental effects. Determination of whether this assumption is correct requires monitoring and evaluation of the effectiveness of the components and systems incorporated in designs against the *design objectives*. The outcomes of such monitoring and evaluation should be fed back to designers so that they can adopt assumptions that are as realistic as possible in their design approach. This is as true for fire engineering as it is for any other branch of engineering.

In considering the use of fire safety components, sub-systems and systems in buildings, whether by way of regulatory requirements, deemed-to-comply

*E-mail: ian.thomas@vu.edu.au

1042-3915/02/02 0063–16 $10.00/0 DOI: 10.1106/104239102024784

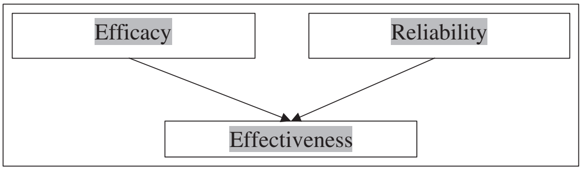

Figure 1. *Effectiveness.*

provisions or engineering design, it is useful to have some idea of the effectiveness of each system. This allows some comparison of the systems to be made and may serve as a basis for balancing requirements for one provision against another, that is, offsetting the provision of one system against a reduced (or even no) requirement for another system.

A concept of *effectiveness* that will be useful in this context is simply described in Figure 1.

If we define *effectiveness* as a combination of two factors, efficacy and reliability, then we can begin to obtain some interesting insights using statistical and other historical data.

Defining *efficacy* as the degree to which a system achieves an *objective* given that it operates, it is obvious that the efficacy of a system may be different depending on the objective. For example, if a fire safety system (such as sprinklers, smoke or heat detectors or fire resistant barriers) is intended to prevent fatalities, its efficacy is:

- 100% if there were no fatalities whenever it was present and operated.
- between 0 and 100% if the rate of fatalities whenever it was present and operated was reduced compared to otherwise identical situations with that system not present.
- 0% if the fatality rate remained the same whether it was present or not.
- negative if the fatality rate increased in fires when it was present and operated.

It is foreseeable that the efficacy with regard to another objective, for example avoidance of property damage, might be quite different. A negative efficacy would result if the operation of the system increased the occurrence of unwanted outcomes.

Defining *reliability* as the probability that the system operates when required, a fire safety system would be 100% reliable if it operated as required every time it was required and 0% reliable if it never operated when required. Under this definition, reliability is obviously unaffected by the objective and thus is the same regardless of the objective.

Thus, *effectiveness* as a combination of efficacy and reliability depends on the objective under consideration, and therefore is not necessarily the same for each objective. This definition of effectiveness exposes a common (usually unstated) assumption, that reliability and effectiveness are identical. However, it is obvious that a system can be very reliable but still be ineffective with respect to a particular objective.

It is useful to try to obtain some idea of the effectiveness of commonly used fire safety systems using the fire record by looking at how the use of fire safety systems changes things like the fatalities and the property losses, or any other measure reflecting specific objectives that might be important in fire safety regulation or engineering.

There are some difficulties in actually doing this that need to be understood. Firstly, virtually the only accessible fire records are of those fires attended by the fire brigade. However, it is well understood that there are far more fire starts than those attended by the fire brigade. Swiss [1] and British data [2] indicate that there are probably between five and ten times as many fire starts as there are fires reported to the fire brigade. This indicates that very many of these fires self-extinguish while small or, perhaps more likely, are dealt with successfully by the building occupants. This hypothesis is supported by the fact that, even when the fire brigade is called, detectors and sprinklers very often do not operate. Table 1 indicates the proportions of fires where detectors or sprinklers *did not operate* (for whatever reason) obtained from the USA NFIRS database for a variety of occupancies [3]. Note that these percentages are not just of fires where the occupants or someone else called the fire brigade before the detectors or sprinklers operated, but that they had not operated when the fire brigade arrived and the fire was extinguished, whether by the occupants, the fire brigade or otherwise. Note also that in most cases the fire brigade did *not* record that in their judgement the detectors or sprinklers had failed, rather that the fire was too small, so these figures *do not* necessarily indicate unreliability of detectors or sprinklers.

The figures in Table 1 are very consistent – for each occupancy, the percentage of detectors in the room or space of fire origin that did not operate is always less than the percentage of detectors not in the room or space of fire origin that did not operate and, except for Manufacturing and Storage, this percentage is less than that of sprinklers that did not operate. The respective percentages across the various occupancies are also very consistent.

Secondly, there needs to be a large number of fires in the database for it to be possible to estimate some of the quantities with confidence. In most residential occupancies, injuries only occur in about fifty, and fatalities only occur in about five in every 1000 fires notified to the fire brigade. Thus, to estimate the rates of injuries or fatalities with reasonable accuracy, there needs to be at least a thousand or so fires for injuries and several thousand fires for fatalities. In non-residential occupancies, the number of fires

Table 1. Proportion of fires reported to the fire brigade with detectors or sprinklers present that did not operate.

% of Fires Reported to Fire Brigade When Detector or Sprinkler Did Not Operate			
Occupancy (FPU)	**Detectors in Room (DP3 + DP5)/ (DP1 + DP3 + DP5)***	**Detectors Not in Room DP2/ (DP2 + DP4)***	**Sprinklers SP1/ (SP1 + SP2 + SP3)***
Public Assembly (100–189)	49	57	72
Educational (200–249)	36	51	81
Institutional (300–369)	34	37	87
1 and 2 Family Dwellings (410–419)	~40	~50	~60
Apartments (420–429)	36	39	60
Rooming and Boarding (430–439)	31	34	70
Hotels and Motels (440–449)	30	38	78
Dormitories (461–469)	18	24	70
Retail (510–589)	50	56	69
Offices (591–594)	35	52	78
Manufacturing (700–799)	30	56	52
Storage (800–899)	37	55	51

*See the following section for details of detector and sprinkler categories.
Data from USA NFIRS data [3] as follows:
Public Assembly, Educational, Institutional, Rooming and Boarding, Hotels and Motels, and Dormitories: 13 years from 1983 to 1995.
1 and 2 Family Dwellings: in Table 1 1983 and 1995, elsewhere 1983–1995.
Apartments and Retail: 10 years from 1983 to 1993 excluding 1986.
Offices: 1983–1991.
Manufacturing and Storage: 1983–1993.

required to estimate the rate of fatalities is higher because fatalities generally occur in less than one fire in every 1000 fires reported. If there are not enough fires, it is impossible to accurately estimate injury or fatality rates. A similar problem occurs, but to a lesser extent, with property loss rates – fewer fires are needed but still a large number of fires is required for accurate estimates.

Thirdly, the fire database records very few "inputs" to the fires. In particular, few details are recorded of fire safety systems – whether they are present or not, whether they operated as intended, etc. (if indeed it is possible to observe this after the fire has been extinguished). Most of the items recorded in the database are "outputs" of the fires – how far smoke spread, how widespread flame damage was, how many injuries and fatalities occurred, the estimated property $ loss, etc.

However, there are some useful "input" items recorded along with several "output" items that relate to objectives that are relevant to building regulations and fire engineering. These are dealt with in the next section.

ESTIMATES OF EFFECTIVENESS

The data available to the author provides details of nine to thirteen years of data from 1983 depending on the occupancy from the USA NFIRS database for a range of occupancies (see Table 1 for details). The data has been scanned and the number of fires and the numbers of firefighter and civilian casualties (injuries and fatalities) and the total estimated $ loss recorded for combinations of three useful "input" variables [4]. The input variables are the *absence* or *presence* of *sprinklers*, *detectors* and *protected construction*. The data for all of the fires where one or more of these variables has been recorded as unknown, etc. have not been included in the tables that follow. Analyses incorporating the "unknown, etc." data are more complex but show similar results to those below.

The data records the performance of *sprinklers* in terms of the following categories:

SP1 Equipment operated
SP2 Equipment should have operated but did not
SP3 Equipment present but fire too small to require operation
SP8 No equipment present in room or space of fire origin
SP9 Unknown, etc.

The definition of SP8 implies that, for SP1, SP2 and SP3, sprinklers were present in the *room or space of fire origin*. The division between SP2 and SP3 requires judgement on the part of the firefighter completing the report. Although it has been shown elsewhere that this judgement generally seems to be exercised judiciously, there are cases where the recorded *extent of flame damage* appears to be inconsistent with the sprinkler performance classification. Consequently, in what follows three sprinkler classifications have been used:

- Sprinkler not present: SP8
- Sprinklers present: SP1, SP2 and SP3
- Sprinkler presence unknown: SP9

Similarly, the classification of detector performance is as follows:

DP1 Detector(s) in the room or space of fire origin and they operated
DP2 Detector(s) not in the room or space of fire origin and they operated

DP3 Detector(s) in the room or space of fire origin and they did not operate
DP4 Detector(s) not in the room or space of fire origin and they did not operate
DP5 Detector(s) in the room or space of fire origin but fire too small to require them to operate
DP8 No detectors present
DP9 Unknown, etc.

For reasons similar to those explained for sprinklers, these definitions are used as follows:

- Detectors not present: DP8
- Detectors present: DP1, DP2, DP3, DP4 and DP5
- Detector presence unknown: DP9

The data records the performance of *protected construction* in terms of the following categories:

CT1 Fire resistive (BBC Types 1A, 1B; SBC Type I; UBC Type I)
CT2 Heavy timber (BBC Type 3A; SBC Type III; UBC Type III (HT))
CT3 Protected non-combustible or limited combustible (BBC Types 2A, 2B; SBC Types II, IV (1 h); UBC Types II, IV (1 h))
CT4 Unprotected non-combustible or limited combustible not qualifying for CT3 (BBC Type 2C; SBC Type IV; UBC Type IV (N))
CT5 Protected ordinary (BBC Type 3B; SBC Type V (1 h); UBC Type III (1 h))
CT6 Unprotected ordinary not qualifying for CT5 (BBC Type 3C; SBC Type V; UBC Type III (N))
CT7 Protected wood frame (BBC Type 4A; SBC Type VI (1 h); UBC Type V (1 h))
CT8 Unprotected wood frame not qualifying for CT7 (BBC Type 4B; SBC Type VI; UBC Type V (N))
CT9 Not classified above, unknown, etc.

In the above, the classifications (in brackets) are USA model building code classifications included in each category. “BBC”, “SBC” and “UBC” designate the Basic Building Code, Standard Building Code and Uniform Building Code respectively [5–7]. Categories CT1, CT3, CT5 and CT7 incorporate protected construction (thus “Y” for Protected Construction below) and CT4, CT6 and CT8 are unprotected (thus “N” for Unprotected Construction). In the USA category, CT2 “Heavy Timber” is generally thought of as fire resistive but, in this paper, this category has been excluded from consideration (that is, has not been included in either protected construction or unprotected construction) to avoid any doubt about this.

Effectiveness in Reducing Fire Spread

In the NFIRS database, the *extent of flame damage* is recorded under the following categories:

EFD1 Confined to the object of origin
EFD2 Confined to part of room or area of origin
EFD3 Confined to the room of origin
EFD4 Confined to the fire-rated compartment of origin
EFD5 Confined to the floor of origin
EFD6 Confined to the structure (building) of origin
EFD7 Extended beyond structure of origin
EFD0 Unknown, etc.

It is generally accepted that, the greater the fire spread, the greater the risk to building occupants. This is supported by a study of the database by the author that revealed civilian fatality rates for residential occupancies were generally:

- less than one per 1000 fires for flame damage confined to the object of origin.
- less than five per 1000 fires for flame damage confined to the area or room of origin.
- about twenty or more per 1000 fires for flame damage beyond the room of origin.

The NFIRS data provides an estimate of the extent of fire spread and this may give some indication of the effectiveness of the identified fire safety systems in preventing or reducing fire spread. Figure 2 shows Pareto charts of the percentage of fires with flame damage that extended beyond the room of origin for various combinations of the presence (Y) or absence (N) of sprinklers, detectors and protected construction in that order for a wide variety of occupancies. Thus NNN means none of them were recorded as present, YYY means all were recorded as present and, for example, YNN meaning that sprinklers were recorded as present but detectors and protected construction were not.

Examination of Figure 2 shows:

- the percentage of fires with flame damage beyond the room of origin varies widely with occupancy, and for each occupancy with various combinations of sprinklers, detectors and protected construction;

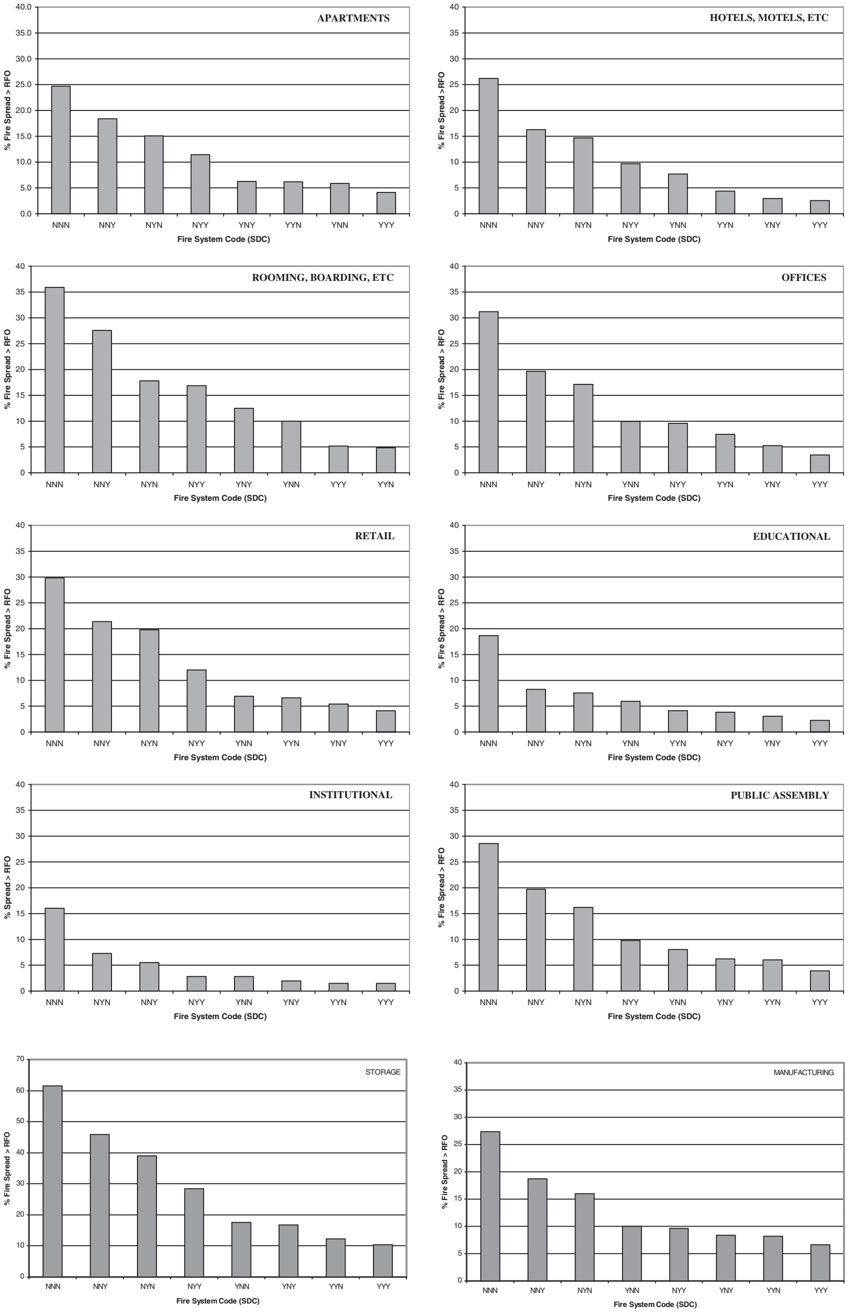

Figure 2. *Pareto charts of fires with flame damage beyond room of origin.*

- there is a great deal of consistency in the order of the combinations for each occupancy (from greatest to least percentage), with no sprinklers, detectors or protected construction (NNN) always having the largest percentage and all three present (YYY) having the lowest in all but one occupancy;
- in almost all cases, for the combinations with sprinklers present, the percentage of fires with flame damage beyond the room of origin was less than for those without sprinklers;
- the effectiveness of the individual systems in reducing the percentage of fires with spread beyond the room of origin (compared with the NNN case) based on these figures varies between 0.60 and 0.82 for sprinklers, between 0.34 and 0.66 for detectors and between 0.23 and 0.59 for protected construction;
- in all occupancies, having sprinklers alone was generally significantly better and never significantly worse than having *both* detectors and protected construction;
- in all occupancies, there was some (but often very slight) advantage in having sprinklers plus detectors and protected construction compared with just having sprinklers.

Further examination of the data for Apartments, Rooming and Boarding shows that the effectiveness of the individual systems (compared with the NNN case) in reducing the proportions of fires with flame damage in categories EFD6 and EFD7 varies similarly: 0.87 and 0.76 for sprinklers, 0.46 and 0.56 for detectors and 0.32 and 0.48 for protected construction. Thus, it appears that the effectiveness comparison applies not just to limiting fire spread to the room of origin, but for wider fire spread also.

Effectiveness in Reducing Death, Injury and Property Loss

In the design of buildings for fire safety, an objective of minimizing fire spread is likely to be a secondary objective stemming from primary objectives such as minimizing (or avoiding if that were possible) casualties among the occupants and firefighters, and minimizing property damage. Other primary objectives are also possible.

It is possible to use the data from the NFIRS system to compare the outcomes of fires for the various occupancies and with the various combinations of sprinkler, detector and protected construction presence in regard to the number of firefighter and civilian casualties and estimated property losses. A summary of the number of fires, casualties and estimated property losses has been developed [4]. However, it is very difficult to make comparisons or draw meaningful conclusions because of the different numbers of fires in each category and so this data is presented in Table 2 as *rates* (casualties per 1000 fires) for several casualty categories and as the average estimated $ loss per fire representing the estimated property damage.

In examining the results in Table 2, it is important to keep in mind the number of fires on which the data is based for each occupancy and each combination of sprinklers, detectors and protected construction. In some cases, there is a very large number of fires. In these cases, a great deal of confidence can be placed on the casualty numbers, damage and rate figures. However, in some cases, there are relatively few fires and, in these cases, caution must be exercised in drawing conclusions from the casualty and rate figures. The shaded cells in Table 2 indicate rate of civilian fatality figures that should be viewed with particular caution.

Examination of Table 2 shows that the *rate of firefighter injuries* varies between 4.8 and 204 per 1000 fires with an average of about fifty and the *rate of civilian injuries* between 4.8 and 133 per 1000 fires also with an average of about fifty. *Firefighter fatalities* are very infrequent and, in most cases, no meaningful rate can be calculated, but for *civilian fatalities* the rate varies between 0.1 and 39.5 per 1000 fires. In many cases, there were no civilian fatalities, but care must be exercised in such cases to look at the number of fires that have occurred in that category as, in many cases, the number of fires is so low that there would not be expected to be any fatalities even if the fatality rate was quite high.

Each of the rates in Table 2 can be considered to be associated with a specific objective – minimization of each category of casualties and minimization of property damage. Thus the figures can be thought of as reflecting the "effectiveness" of the individual and combined fire safety systems present.

Careful examination of Table 2 shows that there are significant and systematic variations in the rates between the occupancies and with different combinations of sprinklers, detectors and protected construction. Looking at the rate of civilian fatalities (and disregarding the zeros in shaded cells) it may be seen that the rates for non-residential occupancies are generally below 2.0 fatalities per 1000 fires with an average of just over one. In contrast, the rates for the residential occupancies vary more widely, from as low as about two for Dormitories to as high as over thirty for Rooming and Boarding. More typical rates for residential are about eleven fatalities per 1000 fires for 1 and 2 Family Dwellings and about nine fatalities per 1000 fires for Apartments, with Institutional being about four (Institutional, which is semi-residential, is included here in this "residential" group).

The variation in the firefighter injury rates and civilian fatality rates is generally from higher to lower values from the left to right sides of the table,

Table 2. Rates of casualties and property losses for various occupancies and fire safety systems (code refers to sprinklers, detectors, protected construction, see text).

Occupancy	Code*	NNN	NYN	NNY	NYY	YNN	YYN	YNY	YYY
Public Assembly	Fires	23809	5303	19760	6397	1997	1896	3266	5115
	RFFI	62.5	56.4	51.7	35.6	28.5	14.2	23.6	11.3
	RCI	18.1	26.0	23.3	30.0	40.6	25.3	36.4	31.9
	RCF	1.3	1.3	1.3	0.5	0.0	0.0	0.0	0.0
	AE$L	22492	21767	16555	13249	7924	5036	6857	3934
Educational	Fires	4240	2836	7548	7041	208	723	583	3289
	RFFI	40.3	38.8	27.2	27.0	4.8	16.6	12.0	7.6
	RCI	25.9	36.0	33.4	35.8	4.8	80.2	25.7	51.7
	RCF	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.6
	AE$L	21220	18735	11439	7806	7705	2588	3493	3146
Institutional	Fires	1618	3144	4406	10246	185	1229	2292	18023
	RFFI	41.4	23.2	17.2	20.8	27.0	11.4	9.2	10.6
	RCI	36.5	97.3	73.1	83.3	70.3	60.2	72.4	77.4
	RCF	4.3	8.3	1.1	4.0	5.4	0.0	2.2	1.9
	AE$L	6114	4137	3361	2703	848	5104	1173	1567
1 and 2 Family Dwellings	Fires	522670	280409	273496	192278	457	426	2977	3533
	RFFI	36.5	31.8	36.1	29.9	19.7	21.1	25.9	18.4
	RCI	43.6	48.5	49.3	52.3	48.1	37.6	32.2	16.4
	RCF	11.6	5.9	9.5	4.7	10.9	7.0	4.0	5.1
	AE$L	7540	7126	7443	7178	8180	7246	6265	6298
Apartments	Fires	42666	51988	53075	78795	389	3134	1290	9070
	RFFI	54.9	59.5	43.3	35.9	36.0	17.2	24.8	14.6
	RCI	65.5	86.8	71.4	84.1	28.3	36.1	30.2	55.2
	RCF	9.4	8.7	7.4	6.8	2.6	1.3	2.3	2.8
	AE$L	8451	6808	5520	5428	3613	5160	1847	2713
Rooming, Boarding, etc	Fires	1240	1803	764	1310	10	188	16	244
	RFFI	91.1	93.7	74.6	55.0	0.0	117.0	0.0	8.2
	RCI	84.7	133.1	98.2	100.8	0.0	69.1	62.5	82.0
	RCF	39.5	30.0	15.7	28.2	0.0	21.3	0.0	0.0
	AE$L	11809	7869	8098	5986	7973	8984	11246	1733
Hotels and Motels	Fires	2627	2669	3130	5126	108	540	444	4011
	RFFI	45.3	63.3	28.4	40.4	55.6	22.2	18.0	12.7
	RCI	58.6	107.5	67.4	96.2	0.0	44.4	49.5	62.3
	RCF	4.2	11.6	4.8	6.8	0.0	3.7	0.0	1.2
	AE$L	12750	16652	6224	10050	3731	3508	6160	3149
Dormitories	Fires	410	1023	639	3588	21	206	130	1295
	RFFI	34.1	21.5	32.9	17.0	0.0	9.7	61.5	13.1
	RCI	56.1	68.4	72.0	60.8	95.2	38.8	61.5	20.8
	RCF	2.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
	AE$L	8530	8498	3867	4466	6285	19778	38906	1101
Retail	Fires	17591	1065	14508	1226	1734	754	3498	2560
	RFFI	74.3	98.6	58.8	44.9	56.5	45.1	34.3	16.8
	RCI	37.1	30.0	24.1	25.3	51.9	46.4	46.6	35.2
	RCF	1.6	0.0	0.9	0.0	0.0	0.0	1.4	0.0
	AE$L	25993	34584	18373	15941	15767	10664	21974	15695

Table 2. Continued.

Occupancy	Code*	NNN	NYN	NNY	NYY	YNN	YYN	YNY	YYY
Offices	Fires	4026	1069	4335	2050	168	257	480	1754
	RFFI	88.4	57.1	57.0	59.0	53.6	38.9	45.8	17.7
	RCI	14.2	13.1	16.6	40.5	11.9	7.8	47.9	37.1
	RCF	1.2	1.9	0.5	0.0	0.0	0.0	0.0	0.6
	AE$L	25832	38614	16388	19550	8730	23261	8356	3898
Manufacturing	Fires	11401	1339	5722	1106	5420	3094	4733	4633
	RFFI	85.5	79.9	87.2	97.6	66.1	50.1	45.0	40.4
	RCI	51.3	49.3	53.8	54.2	68.1	81.8	60.0	78.6
	RCF	1.9	0.7	3.7	0.9	0.9	1.6	0.8	2.8
	AE$L	49385	42908	34680	18714	29517	21903	12061	13317
Storage	Fires	22551	666	5982	345	856	408	716	591
	RFFI	58.8	93.1	94.8	121.7	204.4	63.7	92.2	67.7
	RCI	13.0	37.5	21.7	26.1	29.2	41.7	69.8	32.1
	RCF	1.3	3.0	1.8	0.0	1.2	0.0	0.0	0.0
	AE$L	19365	54437	26220	43921	53275	260809	64001	55747

**Note*:
1. Fires = number of fires, RFFI = rate of firefighter injuries per 1000 fires, RCI = rate of civilian injuries per 1000 fires, RCF = rate of civilian fatalities per 1000 fires and AE$L = average estimated $ loss per fire.
2. Shaded entries should be treated with caution because of low numbers of fires in these categories.

that is from the NNN case to the YYY case, but neither is totally consistent. However, in several occupancies, the civilian injury rate increases, rather than decreases, in the same direction.

It is difficult to absorb and interpret so many figures. Consequently, a least squares regression analysis has been used to analyze the data and to assist in understanding the effect of the various combinations of fire safety systems on each of the rates. The results of this analysis based on all of the data are presented in Table 3. In this table, the results for each occupancy are presented for each of the rate figures – firefighter injuries, civilian injuries, civilian fatalities and estimated $ loss. The figure in the "Base Case" column is the estimated rate (per 1000 fires) with none of the fire safety systems present – no sprinklers, no detectors and no protected construction (NNN). The figures in the columns headed Sprinklers, Detectors and Protected Construction may be interpreted as estimates of the effectiveness of each system, when present alone. The effectiveness is 1.0 if the loss rate is reduced to zero by the system, that is the system is apparently 100% effective, and is 0.0 if the system appears to be totally ineffective, that is there is no change in the loss rate. If the system appears to make the loss rate worse, then the effectiveness is negative, the larger the number the greater the effect. Using the figures in Table 3, the estimated rate equals the base case rate multiplied by (1.0 – estimated effectiveness).

Table 3. Estimated apparent effectiveness of sprinklers, detectors and protected construction.

Objective	Base Case*	Sprinklers	Detectors	Protected
		Public Assembly		
Rate of Firefighter Injuries	62.8	0.49	0.18	0.18
Rate of Civilian Injuries	19.3	− 0.48	− 0.18	− 0.23
Rate of Civilian Fatalities	1.3	0.79	0.24	0.10
Average Estimated $ Loss	22400	0.53	0.10	0.25
		Institutional		
Rate of Firefighter Injuries	28.2	0.36	0.09	0.21
Rate of Civilian Injuries	62.3	0.15	− 0.34	− 0.05
Rate of Civilian Fatalities	4.3	0.60	− 0.60	0.60
Average Estimated $ Loss	5100	0.24	0.31	0.16
		Apartments		
Rate of Firefighter Injuries	58.5	0.45	0.04	0.30
Rate of Civilian Injuries	67.7	0.53	− 0.24	− 0.03
Rate of Civilian Fatalities	9.3	0.54	0.06	0.19
Average Estimated $ Loss	8000	0.33	0.10	0.25
		Hotels and Motels		
Rate of Firefighter Injuries	48.3	0.55	− 0.23	0.40
Rate of Civilian Injuries	63.7	0.59	− 0.54	− 0.03
Rate of Civilian Fatalities	6	1.00	− 0.63	0.40
Average Estimated $ Loss	12700	0.55	− 0.24	0.44
		Offices		
Rate of Firefighter Injuries	84.3	0.34	0.16	0.26
Rate of Civilian Injuries	10.7	− 0.62	− 0.97	− 1.05
Rate of Civilian Fatalities	1.2	0.15	− 0.05	0.68
Average Estimated $ Loss	27500	0.54	− 0.20	0.43
		Manufacturing		
Rate of Firefighter Injuries	89.2	0.36	0.07	0.07
Rate of Civilian Injuries	51.4	− 0.31	− 0.20	0.03
Rate of Civilian Fatalities	1.9	0.57	− 0.16	− 0.54
Average Estimated $ Loss	48800	0.40	0.11	0.30
		Educational		
Rate of Firefighter Injuries	39.2	0.50	0.03	0.28
Rate of Civilian Injuries	26.5	− 0.59	− 0.08	− 0.32
Rate of Civilian Fatalities	0.3	− 1.24	0.48	0.48
Average Estimated $ Loss	20700	0.36	0.14	0.44
		1 and 2 Family Dwellings		
Rate of Firefighter Injuries	36.6	0.27	0.14	0.03
Rate of Civilian Injuries	43.9	0.55	− 0.10	− 0.11
Rate of Civilian Fatalities	11.6	0.07	0.47	0.16
Average Estimated $ Loss	7600	0.11	0.05	0.00
		Rooming and Boarding		
Rate of Firefighter Injuries	98	0.21	0.05	0.37
Rate of Civilian Injuries	94.4	0.44	− 0.32	0.13
Rate of Civilian Fatalities	34.5	0.55	0.02	0.32
Average Estimated $ Loss	11500	0.14	0.28	0.26

(*continued*)

Table 3. Continued.

Objective	Base Case*	Sprinklers	Detectors	Protected
		Dormitories		
Rate of Firefighter Injuries	37	0.07	0.50	0.04
Rate of Civilian Injuries	72.9	0.47	0.11	0.06
Rate of Civilian Fatalities	1.6	0.11	0.29	0.72
Average Estimated $ Loss	12400	−0.16	0.31	0.42
		Retail		
Rate of Firefighter Injuries	50.4	0.34	0.08	0.25
Rate of Civilian Injuries	54.7	−0.49	0.16	0.32
Rate of Civilian Fatalities	1.3	0.11	0.76	0.27
Average Estimated $ Loss	22000	0.12	0.04	0.24
		Storage		
Rate of Firefighter Injuries	62.9	−0.79	0.23	−0.38
Rate of Civilian Injuries	13.3	−1.71	−0.44	−0.71
Rate of Civilian Fatalities	1.37	0.82	−0.06	−0.16
Average Estimated $ Loss	20700	−2.46	−2.43	0.14

*Firefighter injuries, civilian injuries, civilian fatalities per 1000 fires, estimated $ loss per fire, the effectiveness estimates are unitless.

There is one major caution that must be considered in reviewing these numbers – it is easy to assume that the systems considered are *the cause of the changes* in the rates, but this is not necessarily correct. All that can be said is that when these systems are present these changes are apparent, not that they (or that they alone) *cause* the changes. It is possible that there are other systematic changes in the circumstances that vary with the presence or otherwise of these systems that actually contribute to, or even cause, the changes. There are indications that this must be so. Careful analysis of the changes that coincide with the presence of sprinklers in some occupancies have indicated that it is very unlikely that the operation of the sprinklers could have caused the changes – that there must be another factor(s) also. In these cases, the only explanation that seems plausible is changes in the occupants present in each case – that the occupants in sprinklered buildings are, on average, more likely to deal with a fire start effectively than, on average, those in an unsprinklered building.

Reviewing the effectiveness estimates in Table 3, it becomes obvious that there is great variation in the estimated effectiveness for the fire safety systems and for each system between the different occupancies. There are also many cases in which the estimated effectiveness is negative.

Generally, sprinklers have greater estimated apparent effectiveness than either of the other systems for most of the occupancies and objectives, but there is less consistency in these results than in the fire spread results presented in Figure 1. It appears there might be a less direct relationship between reduction in fire spread and casualties than is often assumed.

For the civilian fatality rate, sprinklers are estimated to have an effectiveness greater than 0.5 in about 60% of occupancies, while detectors have such an effectiveness in less than 10% and protected construction in about 20% of occupancies. In several cases, the estimated effectiveness of sprinklers is close to one. Sprinklers have a negative effectiveness in one case, educational, but the number of fires on which this estimate is based is very small (see Table 2) and the fatality rate for educational is exceptionally low for any combination of systems.

Civilian injuries represents an interesting case – for all three systems, the apparent effectiveness is negative for several occupancies. However, for some occupancies, the apparent effectiveness is positive and quite high, particularly for sprinklers. Why this variation between occupancies exists is not obvious. It may also be that there is indeed an increased incidence of civilian injuries with the presence of these systems but it may be that the severity of the injuries is also changed. It is not possible to evaluate the severity of the injuries from the data, so it is not possible to do more than conclude that the presence of these systems sometimes coincides with an increase in the rate of reported injuries.

The firefighter injury case is more clear cut, with the estimated apparent effectiveness for sprinklers being generally greater than that for the other systems by a significant margin, though again there are exceptions. However, it can be concluded that generally the presence of sprinklers coincides with significantly reduced firefighter injury rates.

In terms of the estimated $ loss, sprinklers again generally appear to be more effective than the other systems, but not always. Again, there is wide variation between occupancies with the presence of sprinklers coinciding with a greatly increased loss rate for Storage. This may be associated with, on average, greatly increased size and/or value of the buildings (including contents) for those that are sprinklered, but this possibility requires further data for confirmation.

EFFICACY AND RELIABILITY

The estimates of effectiveness in Table 3 are of limited value in estimating the components of effectiveness – efficacy and reliability. If, in considering the estimates, we assume that the systems are 100% reliable, then we can obtain upper bound estimates of efficacy for each of the objectives. Conversely, if we assume 100% efficacy, then we can obtain a lower bound estimate of reliability from the lowest of the effectiveness estimates for any of the occupancies – though we are not helped in this if the effectiveness in any case is zero or negative. It is planned to combine estimates of reliability from other sources with this data to obtain better estimates of efficacy in the future.

CONCLUSION

It appears from the data and analysis presented that there is useful information contained in the available fire incident database in relation to the effectiveness of some fire safety components and systems. Based on the extent of flame damage data in Figure 2 for all occupancies, it is generally significantly better (and never significantly worse) to have sprinklers alone than to have *both* detectors and protected construction. In all occupancies, there was an advantage (sometimes very small) in having sprinklers plus detectors plus protected construction compared with sprinklers alone.

The limited data available makes it possible only to estimate effectiveness for three fire safety systems: sprinklers, detectors and protected construction. Data on a greater range of components and sub-systems would be very beneficial in that it would enable their effectiveness to be estimated also.

Based on the data analyzed it appears that sprinklers are generally more effective in reducing fire spread and to a lesser extent civilian fatalities, firefighter injuries and property losses than either detectors, protected construction or both detectors and protected construction.

REFERENCES

1. Favre, J.-P., "Design of buildings for fire safety in Switzerland", In: *Proceedings of Seminar on Design of Steel Buildings for Fire Safety*, Australian Institute of Steel Construction, Sydney, 1996.
2. MORI, "Domestic First Aid Fire Fighting Report", Home Office, UK, 1994.
3. National Fire Incident Reporting System (NFIRS). Federal Emergency Management Agency, USA.
4. Thomas, I.R., "Effectiveness of fire safety systems", *Fire Code Reform Centre*, TWG 3 Report, December 2000.
5. Building Officials and Code Administrators International, Inc., *Basic Building Code*, Chicago, IL.
6. Southern Building Code Congress, *Standard Building Code (SBC)*. Birmingham, AL.
7. International Conference of Building Officials, *Uniform Building Code (UBC)*. Whittier, CA.