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TOWARD MORE RELIABLE RESIDENTIAL SMOKE DETECTION SYSTEMS

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SUMMARY

False alarm reductions of 41-75 % were observed at Harvard following installation of new, less sensitive smoke detectors to replace more sensitive ones or by introducing time delays into the system. A new evaluation index for smoke detection systems, based on alarm-free months, showed an increase of 33% in alarmless months following replacement. A model of this index predicts that negligible benefits to some systems can occur following replacement; however, a potentially negligible benefit might be turned into a significant benefit if detectors had adjustable sensitivities.

INTRODUCTION

The false alarm problems associated with smoke detectors have been the subject of papers and reports for more than 20 years[1] and will apparently continue to remain a popular topic[2].

In the early 1980's, many local authorities in the USA mandated the installation of smoke detection systems in the hallways and stairwells of residential property, including college dormitories. The Cambridge and Boston Fire Departments acted as the enforcing authority for Harvard. That was when a serious false alarm problem began at Harvard. Each smoke detection system is connected to the fire alarm system so that the actuation of one smoke detector results in klaxons or bells sounding throughout the building. Prior to any concerted remedial action, there were 133 times at the University when three or more fire alarms occurred in a given month in one building or another among Harvard's 80 dormitories. The total number of alarms within this subset of 133 was 559 alarms and the average number per month per building was 4.21. Approximately 98% of these alarms were false and the balance due to actual fires.

Approximately 85% of these alarms were caused by smoke detectors; the rest were due to automatic heat detectors, manual pull stations and telephone calls.

Two years before remedial actions were taken (1984 and 1985), the average monthly alarms from all 80 dormitories (housing approximately 6,700 residents) was 58. Contributing to these alarms were the 2,600 smoke detectors (95% were photo-electric, factory-set for tripping at a nominal optical density of 0.022 per meter† and meeting the UL 268 Standard[3] [OD .022 m^{-1}], and without field adjustability features). An analysis of 1,438 alarms in a 35 month period from smoke detectors, pull stations, telephone calls, and other devices in this period has shown that the ratio of false alarms to real fires signaled by smoke detectors was 46:1 and that the comparable ratios for pull stations and telephones was 16:1 and 0.3:1 respectively[4]. Calculations at Harvard, based on 1984 and 1985 data, show that each smoke detector had a probability, on the average, of producing a false alarm about once every four and a half years. Known causes of needless alarms are typically kitchen smoke, fireplace smoke, tobacco smoke, dust from custodians sweeping or contractors working, high humidity, steam, aerosols, insects penetrating the detector, automobile exhaust gases and poor maintenance.

The purpose of this study was to determine the best method of reducing false alarms.

† An optical density of 0.022 per meter corresponds to 1.5% smoke obscuration per lineal foot. Other optical densities reported in this paper of .032 OD m^{-1} and .036 OD m^{-1} correspond to 2.2 and 2.5% smoke obscuration per foot.

The Problem

An order of magnitude increase in false alarms followed the initial installation of smoke detection systems in Harvard dormitories more than four years ago. The problem became evident in the attitudes of residents toward these alarms. Increasingly, they left the building much more slowly and, in some infrequent cases, residents ignored the alarms or hid in their rooms. This deterioration in attitude was documented by polling the University Police[5], who respond, along with the municipal fire department, to every alarm, averaging between two and three minutes to arrive at the scene.

The problem associated with false alarms anywhere is the damage done to the credibility of the system. Credibility is not easily quantified. Yet, as Breznitz[6] observes, "two important failures or mistakes of a warning system can drastically reduce its credibility. The law of initial credibility posits that a warning system that enjoyed high credibility will lose more credibility following a false alarm than one whose credibility was lower in the first place. Stated differently, it suggests that those people who took the threat more seriously will have a greater amount of credibility loss following the false alarm information than those who took it less seriously."

It is not unreasonable to assume that after residents hear an alarm which is proven to be false, a second alarm occurring a few hours, days, or even weeks later will be much more strongly suspected of being false than the first one. Therefore, it may be hypothesized that it is the first false alarm which most damages the credibility. Subsequent alarms do little in the near term to erode any residual credibility but, of course, can add greatly to the magnitude of the nuisance. Smoke detectors are supposed to give early warning of fire, but if the credibility of the alarm system has been destroyed, then residents may require a second, more convincing fire threat cue (e.g., seeing flames, smelling smoke, etc.).

It was with credibility in mind that the author chose to evaluate false alarms based on a system index, not individual detectors. It was credibility which led him to count a system's "alarm-free months" and use that count in a new rating index which is psychologically more meaningful because it credits the alarm-free month much more than it gives demerits to months in which multiple alarms have occurred.

Desensitization and Other Options

Desensitization of smoke detection systems through replacement of older, overly sensitive detectors with newer, less sensitive ones was chosen as a relatively recent means to ameliorate the problem in 50 of the 80 dormitories. Less sensitive UL listed detectors were in the marketplace and allowed Harvard this option.

Prior to making this commitment, Harvard decided to evaluate the benefits of desensitization by making sensitivity changes through circuit adjustments to existing smoke detectors in two dormitories with a history of many false alarms. The early desensitization work for two dormitories was contracted to two smoke detector manufacturers, each being assigned a single dormitory. Potentiometrically desensitized detectors were adjusted from a nominal .022 OD m^{-1} to either .032 or .036 OD m^{-1}. Brand A (.036) was installed in a 147 detector dormitory and Brand B (.032) in a 31 detector dormitory. Additionally, alarm verification† modules were added to two other dormitories.

Later, the University obtained "hardened" detectors that had improved resistance to false alarms from entrapped dust, internal light scattering, insect penetration, humidity, steam, and radio interference. These detectors were installed in four other dormitories, thus bringing the total of experimental smoke detection systems to eight in the 1984-1985 period. The hardened detectors retained a nominal .022 OD m^{-1} sensitivity. These five steps are listed in chronological order in Table 1.

† Alarm verification requires a delay in initiating an alarm; it requires a timed confirmation by the system. The system will initiate an audible alarm if a smoke concentration is found to be above the tripping level for both an initial and follow-up monitoring.

Table 1.

Chronological Sequence of Steps to Reduce False Alarms in Dormitories Containing Photoelectric Smoke Detection Systems

Step	Alarm Reduction Method	No. of Buildings	Total No. of Smoke Detectors	New sensitivity of Detectors (obs. ft^{-1})	Duration of Delay (Sec.)
1	Desensitization	1	147	2.5%	—
2	Desensitization	1	31	2.2%	—
3	Alarm Verification	2	118	1.5%*	60
4	"Hardening"	4	113	1.5%*	—
5	Desensitization	50	1508	2.5%	—

* This was the original nominal sensitivity.

Beginning in January 1986, the University replaced .022 OD m^{-1} units with .032 OD m^{-1} counterparts in 50 dormitories. This replacement program involved 1,508 new smoke detectors. The decision to use less sensitive detectors rather than alarm verification or hardened detectors was based on the preliminary trial results given here and reluctance to install automatic delay of an alarm signal when it would have required, in most cases, the same delay on manual pull stations, a condition not allowed under today's standards by Underwriters Laboratories. An annual detector cleaning program has also helped to reduce false alarms.

Results and Analysis

The results of the desensitization by circuit adjustment experiments in two dormitories are shown in Tables 2 and 3. Few readers will doubt that there has been a clear reduction in false alarms.

Table 2 data show that the desensitized detectors afforded: a) an 80% reduction in unwanted alarms when comparing the nine months before desensitization to the nine months immediately following: b) a 69% reduction when comparing the nine months before desensitization to the same nine calendar months after; and c) a 61% reduction in unwanted alarms when comparing the nine months before desensitization to the 25 months following. In the case of this dormitory, with 147 detectors (Table 2), the percent of alarm reduction appears to decline with the passage of time. This observation suggests that when new detectors grow old, they become more sensitive or that annual cleaning techniques are less than perfect.

The results of 60-second time delays using alarm verification modules are shown in Table 4. It is during this time delay that the opportunity exists for smoke or other transients to dissipate below a tripping level of .022 OD m^{-1} and

Table 2.

Fire Alarms from Smoke Detectors Before and After Desensitization

	Month											
Year	J	F	M	A	M	J	J	A	S	0	N	D
1983	-	4	9	4	4	4	4	7	11	1	3*	0
1984	1	1	3	1	0	0	0	3	4	3	2	1
1985	1	2	4	3	7	4	2	1	5	1	1	2

Number of detectors: 147 (Brand A: Desensitized to 0.36 OD m^{-1}) The asterisk identifies the month that desensitization took place; this month is excluded from statistical treatment. Confidence level > 99% that a statistically significant change has taken place based on the F-test. [F_{tab} (2,30) for 0.99 Conf. = 5.39; F_{calc} (2,30) = 8.49]

Table 3.

Fire Alarms from Smoke Detectors Before and After Desensitization

	Month											
Year	J	F	M	A	M	J	J	A	S	0	N	D
1983	-	-	-	4	6	1	6	3	4	7	6	0*
1984	0	3	2	0	1	7	1	0	2			

Number of Detectors: 31 (Brand B: Desensitized to 0.32 OD m^{-1} The asterisk identifies the month that desensitization took place; this month is excluded from statistical treatment. Confidence Level > 99% that a statistically significant change has taken place based on the F-test. [$F_{tab}(1,17)$ for .99 Conf. = 8.40; $F_{calc}(I, I7)$ = 10.23]

thus avoid an alarm. A counter on each module identified how many alarms had been avoided. Alarm verification modules appear to afford a decrease in unwanted alarms of 75% in Dormitory No. 2 (Table 4) and 41% in Dormitory No. 1. However, Dormitory No. 2 has almost twice as many smoke detectors as Dormitory No. 1 and almost a dozen kitchenettes, whereas Dormitory No. 1 has no cooking facilities. Alarm verification has been found less desirable at Harvard University than desensitization of individual smoke detectors because of the time delays from verification that could result in a rapidly developing fire.

The results of the study of 113 transient-hardened detectors, used in four dormitories, are shown in Table 5. The hardened smoke detectors show 50% fewer alarms from unknown causes: this is a logical consequence of reducing alarms from transient disturbances (e.g., radio interference). Such transients would not be identifiable and hence logged in as "unknown." Therefore, the benefit appears to be real. Also, the number of alarms has been cut in half by comparing the twelve months prior to installation with the twelve months following.

Table 6 shows a summary of data for the 50 dormitories where nominal .032 OD m^{-1} detectors were substituted for the .022 OD m^{-1} units. The decline in unwanted or false alarms is 65%, similar to the reductions shown in Tables 2 and 3. The dormitories are arranged in the order of increasing number of detectors in service. Alarm data for the older sensitive smoke detectors are from part of 1984, all of 1985, and, in most cases, part of 1986. Listed are both the number of alarms and the time span in months during which these alarms occurred for both the

Table 4.

Alarm Verification Data (in 1985)

Mo.	Dormitory 1 (44 detectors)		Dormitory 2 (74 detectors)	
	Alarms Heard	Alarms Avoided	Alarms Heard	Alarms Avoided
Mar	4	3	0	5
Apr	0	0	1	8
May	0	0	8	14
Jun	0	0	6	9
Jul	2	0	1	8
Aug	0	0	2	6
Sep	2	0	1	2
Oct	2	0	1	9
Nov	2	6	2	6
Dec	1	0	1	2
	13	9	23	69

Table 5

Alarms Before and After Installation of Hardened Smoke Detectors

Alarms per Month

Year	Type	U or K	J	F	M	A	M	J	J	A	S	0	N	D	Totals
			Month												
1984	N	U	2	4	1	0	1	6	3	0	2	5	4	0*	29
		K	3	0	1	0	2	4	2	1	1	1	1	1*	17
1985	H	U	1	1	1	0	0	0	0	0	2	2	0	0	7
		K	2	2	1	0	0	1	0	0	3	2	2	2	15

Note: No. of detectors: 113. U stands for unknown cause of alarm: K for known: H for hardened detector: N for not hardened. The asterisk denotes the month that replacement took place.

older and newer detectors on a dormitory-by-dormitory basis. The time intervals for comparison of the performance of older and newer detectors in general were about 24-30 months for each, thus affording nearly equal time intervals for comparison.

Analysis of the 50-dormitory study (Table 6) shows that the overall decrease in alarms following replacement of older units with newer ones was 65%, that is:

$$\text{Percent Decrease} = 100\,(734\text{-}255)/(734) = 65\%$$

Another way of evaluating individual detector performance is to calculate the mean time between alarms. By reworking data in Table 6, one can show that the .022 OD m^{-1} devices collectively produce, on average, 320 alarms per year. Since there were 1,508 devices in service, each detector produced 0.2122 fire alarms per year. The reciprocal of this number is the average span between alarms for a given detector, that is, 4.7 years. The comparable number for the .032 OD m^{-1} devices is 13.5 years. Replacement of the more sensitive detectors with the less sensitive units thus results in a gain of 187% based upon time between alarms, that is:

$$G = 100(13.5\text{-}4.7)/4.7 = 187\%$$

On balance, the overall *average gain*, *G'*, in alarmless months per system resulting from installation of the new units was 33%, that is:

$$G' = 100\,(\,1198\text{-}901\,)\,/901 = 33\%$$

This measure of comparative smoke detection system performance is based on alarmless-months. It is a new method to rate smoke detection systems, not individual smoke detectors, and does not count subsequent alarms from a building's smoke detection system within the same month. For example, this rating method would tend to deemphasize the false alarms coming every other day from a defective detector.

The data in Table 6† were also used to calculate an *Alarm Improvement Index I*, for each dormi-

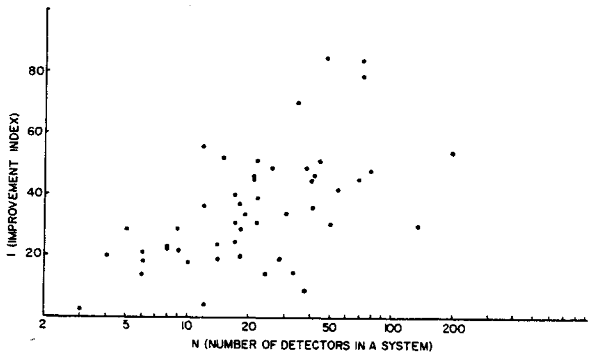

Figure 1. Improvement Index following replacement of 0.22 OD m^{-1} smoke detectors with 0.032 OD m^{-1} detectors as a function of the number of detectors in the system.

† The data in Table 6 were corrected where necessary by extrapolation for slightly unequal times of service in each dormitory for the two types of detectors using the following formula:

$$\text{Total alarms} = \sum_{i=1}^{50} (F_{.032})_i \frac{X_i}{Y_i} = 255$$

Here F.032 is the number of fire alarms *occurring* in building i with .032 OD m^{-1} detectors in service, X_i and Y_i are the corresponding time intervals where .022 and .032 OD m^{-1} detectors were in service, respectively. Of the 250 fire alarms reported in Table 6, six were due to actual fires and the rest were false.

Table 6.

Comparison of Zero Alarm Months for New (.032 OD m^{-1}) Smoke Detectors (Beginning ca. Jan, 1986 and Ending Aug 1, 1988) vs Older (.022 OD m^{-1}) Smoke Detectors (During the period of ca. 1984 - 1986)

Bldg	No. of SDS	Alarms In Time Span X	X (mos)	X' (mos)	P_x	Alarms In Time Span Y	Y (mos)	Y' (mos)	P_y	100(Y'/Y - X'/X)
a	3	1	28	27	.90	5	26	22	.61	– 12
b	4	2	24	22	.77	1	31	30	.91	5
c	4	2	25	23	.78	1	31	30	.91	5
d	5	9	28	22	.49	2	27	25	.79	14
e	6	4	24	21	.67	3	31	28	.74	3
f	6	8	25	21	.59	3	31	28	.74	6
g	6	3	25	22	.68	4	31	27	.66	– 1
h	8	2	25	23	.78	0	31	31	1.00	8
i	8	3	24	22	.77	0	31	31	1.00	8
j	9	4	28	24	.63	2	27	25	.79	7
k	9	11	28	23	.55	1	27	26	.89	14
l	10	3	28	25	.71	2	27	25	.79	3
m	12	10	26	16	.23	5	28	23	.55	21
n	12	22	25	13	.14	2	28	26	.80	41
o	12	4	27	24	.70	22	27	21	.47	– 11
p	14	6	31	26	.59	3	24	21	.67	4
q	14	4	24	21	.67	1	31	30	.91	9
r	15	30	26	8	.03	10	28	19	.31	37
s	17	13	26	16	.23	7	28	20	.36	10
t	17	10	28	19	.31	4	27	25	.79	25
u	17	11	26	18	.33	4	28	24	.63	16
v	18	4	26	22	.61	3	28	25	.71	5
w	18	11	28	19	.31	5	27	22	.54	4
x	18	14	24	14	.20	6	31	25	.52	22
y	19	8	25	21	.59	1	31	30	.91	19
z	21	18	25	12	.11	6	29	23	.50	31
a'	21	12	26	17	.28	1	29	28	.90	31
b'	22	6	26	20	.46	2	29	27	.81	16
c'	22	10	26	18	.33	2	29	27	.81	24
d'	22	20	26	13	.13	5	29	25	.64	36
e'	24	3	27	25	.79	5	28	26	.80	0
f'	26	21	27	15	.17	3	28	25	.71	34
g'	28	11	31	26	.59	3	24	21	.67	4
h'	30	15	27	19	.70	3	28	25	.71	19
i'	33	6	31	27	.66	4	24	21	.67	0
j'	34	28	30	11	.05	2	24	22	.77	55
k'	37	13	29	21	.38	10	27	18	.30	– 6
l'	38	30	26	12	.10	6	24	19	.50	33
m'	40	20	29	18	.24	2	26	24	.79	30
n'	41	21	30	17	.18	5	24	21	.67	31
o'	41	21	25	15	.22	8	31	25	.52	21
p'	44	20	28	14	.13	4	28	24	.63	36
q'	47	58	24	3	.00	9	32	26	.54	70
r'	50	12	27	16	.21	14	28	21	.42	16
s'	54	14	29	19	.28	2	27	25	.79	27
t'	68	22	26	12	.10	9	29	22	.44	30
u'	71	9	33	6	.01	6	22	18	.55	64
v'	78	32	33	15	.09	9	24	19	.50	34
w'	136	64	33	10	.03	20	22	10	.09	15
x'	199	49	30	8	.02	13	26	17	.28	39
	1508	734	1358	901		250	1388	1198		

X = number of months of service with 0.022 OD m^{-1} detectors.
X' = months in time span X in which no alarms occurred.
Y = number of months of service with .032 OD m^{-1} units.
Y' = months in time span Y in which no alarms occurred.
P_x and P_y = probabilities of zero alarms in 3 months for .022 and .032 detection systems (i.e., $P_x = [x'/x]^3$ and $P_y = [y'/y]^3$)

tory, based on the formula:

$$I = 100\,(Y'/Y - X'/X) \tag{1}$$

Where X'/X and Y'/Y are the probabilities of an alarm-free month before and after replacement, respectively. The greater the index, the greater the differences between the detectors before and after replacement. Values of I as a function of N are plotted in Figure 1.

It is seen that considerable scatter occurs.† Four values of I were originally negative; for visual simplification all values were made positive in Figure 1 by adding 15 to the original value of I, given in Table 5. The individual values of the new I range from 3 to 85.

MODELLING

Modelling of this trend suggests that an incremental decline in I can occur above a given value for N. This can be shown by redefining the probabilities associated with alarm-free months before and after replacement (X'/X and Y'/Y, respectively) as the difference between two Poisson distributions. A Poisson distribution is:

$$P\,(n) = \frac{(N\,r)^n}{n!}\,e^{-Nr} \tag{2}$$

Here $P(n)$ is the probability that n alarms will occur in a given month, N is the number of detectors in the system and r is the probability that a detector will cause an alarm in a given month.†† The index I for alarm-free months can be represented by the difference between the two probabilities:

$$I = 100\left[P_2\,(0) - P_1\,(0)\right] = 100\left[e^{-Nr_2} - e^{-Nr_1}\right] \tag{3}$$

where $P_2(0)$ is the Poisson probability that zero alarms will occur in a given month with the new, less sensitive detectors, $P_1(0)$ represents the probability that zero alarms will occur in a given month with the older, more sensitive detectors; r_1 and r_2 are the monthly alarm rates per detector for the old and new detectors, respectively.

If the model is valid, then the maximum value of I for a given size of system, N, and the sensitivity reduction factor ($a = r_1/r_2$) afforded by the replacement effort, is calculable by taking the derivative of I with respect to N, setting it equal to zero and solving for N, that is:

$$\frac{dI}{dN} = -\,r_2 e^{-r_2 N} + a r_2 e^{-a r_2 N} = 0. \tag{4}$$

Solving for N at I_{max}†, we obtain

$$N_m = N_{I_{max}} = \frac{ln(a)}{r_2(a-1)} \tag{5}$$

For example, if $r_2 = 0.0104$ (one alarm per detector, on average, every eight years) and $a = 2$ (thus r_1 signifies one alarm per detector every four years), $N = \ln(2)/0.0104 = 67$. Substituting $N = 67$ in Equation 3 gives $I_{max} = 25$.

How rapidly I approaches zero as a function of N after reaching a maximum and how high its maximum value can become are dependent on the parameters a and r_2. More specifically, the greater the parameter a and the smaller the value of r_2, the greater the area under the curve of Equation 3 and hence the more significant or noticeable the gain in alarm-free months and the greater can be the allowable value of N before I decreases to some unacceptable level, say 50% of I_{max}†† or $I \leq 20$.

† The scatter could probably have been reduced if the dormitories had been stratified by population type (e.g., freshmen dormitories vs. graduate dormitories, similar HVAC systems, similar architecture, percent occupancy, etc. However, these factors were not easily determinable and hence the data in Figure I is unrefined.

†† For example, in a 50 detector system, where each detector has a probability of producing, on the average, one alarm every 4.7 years, (0.0177 alarm per month), the expected number of alarms per month in a given year are: 4.95 months of zero alarms; 4.38 months of one alarm; 1.94 months of two alarms and 0.74 months of three or more alarms. We are more concerned here with alarm free months than with the number of alarms occurring in a month.

† It can be shown that a maximum and not a minimum is occurring at $N_m = \ln(a)/r_2(a-1)$ by calculating d^2I/dN^2 and noting that this second derivative is less than zero at N_m.

†† For example, if $a = 5$ and $r_2 = .02$, $I_{max} = 53$ and the two values of N corresponding to 50% of I_{max} (i.e., 26.5) are 4 and 66. On the other hand, if $a = 5$ and $r_2 = .001$, then I_{max} stays equal to 53, as before, but the value of N corresponding to N_m is 402 and the two values of N corresponding to 50% of I_{max} are 85 and 1325. The half width of the I band is thus much broader when a/r_2 is relatively large.

The part of the curve to the left of the maximum tells us how much we are gaining with a replacement program in a system with fewer detectors than required to attain I_{max}; the portion of the curve to the right of I_{max} also tells us how much we are gaining but it also tells us our system has more detectors in it than some optimum size for N and how much we are losing in comparison to I_{max}†.

The index I can be zero in systems of any size that experience a large number of alarms before and after replacement. For example $I = 0.0$ for a system which initially produced four alarms per week and only two per week following replacement.

These calculations suggest that field adjustability of sensitivity on detectors should be returned to the buyers and installers of systems so that, with the assistance of fire protection professionals, they can match the sensitivity of the detector to the size of the system and the environment that interfaces with the system. More importantly, as the sensitivity of a smoke detection system decreases, the amount of "assured safe egress time" decreases, and this has to be evaluated. Therefore, matching the sensitivity of the detectors purely to the size of the system would not make sense, especially if life safety and not property protection were the dominant concern.

There is obviously a limit to how insensitive a system should be and still afford warning of fire sooner than an automatic sprinkler system. The negative implications revealed by modelling a large, false-alarm prone system may sometimes be counteracted by zoning or subdividing a large smoke detection system into a number of smaller ones, thus allowing more sensitive detectors to be in service. This is not a new concept in life safety. Another countermeasure is that smoke detector manufacturers work harder to develop more discriminating systems which can be programmed to reject specious "smoke" signatures and thus create a more reliable and credible alarm system. To this end, Underwriters Laboratories has devoted considerable time within the last few years to develop more stringent UL 268 standards to mitigate the false alarm problem.

† These calculated values of I are more theoretical than practical since r_2 most likely has to be determined after a period of actual experience, as was done at Harvard.

CONCLUSIONS

The number of alarmless months afforded by the newer, less sensitive units was used to calculate the probability that each of the 50 buildings would experience three consecutive months without an alarm from a smoke detector. These probabilities, given in Table 6, show that eleven buildings have less than a 50% chance of achieving this goal and one dormitory has less than a 25% chance. Again, more work by smoke detector manufacturers and fire protection engineers is needed to reach this goal.

Clear evidence of a significant reduction in false alarms was revealed in a total of 58 dormitories where hardening, alarm verification and desensitization of smoke detectors were separately employed.

Three methods were used to compare older and newer smoke detectors and systems on a percentage basis: (a) mean detector times to alarm (a 187% gain for 50 systems); (b) reduction in false alarms (a 65% gain for 50 systems, a 41-75% gain for eight others); and (c) the increase in alarm-free months (a 33% gain for 50 systems).

DISCUSSION

Methods (a) and (b), discussed above, deal with the aggregate number of smoke detectors in service and the aggregate number of alarms they produce. Method (c) is based on a smoke detection system performance. This last method essentially treats months in which multiple false alarms have occurred in the same way as months in which only one alarm has occurred. In this sense it tends to deemphasize the significance of false alarms which reoccur close in time to each other. It relies on the difference in the probabilities of an alarm-free month before and after replacement for any given building (system) and may therefore be a more effective psychological yardstick of the restoration (or loss) of credibility.

However, the monthly improvement index will be low for systems which already enjoy a low frequency of alarms (e.g., reduction from two alarms per year to one) or for systems which continue to have a high frequency of false alarms after replacement (e.g., reduction from two alarms per week to one). In the former case, the credibility of the system can be considered high to begin with, so that further desensitization might be considered unnecessary; in the latter case, the remedial action has been insufficient.

It should also be pointed out that the development of the improvement index given earlier is simplistic. The model was developed with an alarm environment in mind which was often disturbed by false alarms and virtually never disturbed by real fire alarms. Obviously, credibility assessments of a system by residents are going to be more complicated if, say, one out of four alarms in a month, on average, is due to a life-threatening fire. In other words, there is some restoration of credibility whenever residents learn that the system warned them of an actual fire even though 75% of the alarms are known to be false. The ratio of false alarms to real fires signalled by smoke detectors following replacement in the 50 system study was 42:1, based on six fires. It would thus appear that the great majority of alarms are false and that a more complicated model is not justified at this time.

Although not tested in this work, it is expected that a combination of alarm verification and desensitization or cross zoning and desensitization would result in still greater reduction of unnecessary alarms. The use of more discriminating[7] or "smart" smoke detectors and fire alarm control panels[8] that can evaluate and reject false smoke signatures or electronically compensate detectors which would ordinarily experience gradually increasing sensitivities is also a great source for unwanted alarm reduction, although some of the combinations given will further reduce the so-called "assured safe egress time" and are therefore controversial.

The increase in the number of alarmless months in a residential building following smoke detector replacement in the detection system may be taken as an arbitrary measure of the restoration of alarm credibility. That is to say, residents who do not hear a false alarm after, say, three or more months may be more inclined to heed the warning of the fire alarm system than those who have heard one or more false alarms in the previous three months. On this hypothetical basis, the probability calculations show that eleven out of 50 dormitories with new smoke detectors in service continue to have less than a 50% chance of experiencing three consecutive alarm-free months. This finding indicates that additional improvement in smoke detector and alarm technology is needed to restore full, widespread credibility to all systems.

It is hoped that new smoke detector technology will eventually abate this exacerbating false alarm problem. Field adjustability of detectors may help and ought to be reintroduced to the market.

The work presented here is from a case study. It thus should not be used to quantitatively predict the outcome of a similar replacement program at other universities or residential properties. In addition, the percentages of alarm reduction might not be reproducible at Harvard — if such retesting were possible — due to hidden variables, operative in the two experimental trials to a greater extent in one case than the other.

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