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Improving the Waking Effectiveness of Fire Alarms in Residential Areas

T Grace

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ABSTRACT

The objective of this study is to find ways of improving the waking effectiveness of fire alarms mainly in residential areas. The main goal is to find out why fatalities are occurring when occupants are sleeping, by analysing sleep characteristics, fire alarm characteristics, human arousal and reasons for not waking up or taking any action during an emergency fire alarm signal.

This report describes the sleep characteristics of humans and shows the difference in sleep patterns with age and gender. It then covers the fire alarm characteristics and how the sound can affect awakenings from sleep. It includes fire alarm characteristics and looks at how different frequencies, loudness and sound patterns affect human arousal during sleep.

This report then looks at factors affecting awakenings such as people affected by drugs, alcohol, sleep deprivation and hearing impairment and how this affects the sleep patterns. Also it looks at solutions to lowering the awakening thresholds such as motivational training.

The following section looks into human behaviour in fires such as how and why people react in a fire emergency. Then it looks at statistics from various countries and compares fire trends such as time of fatalities and regions where fires occur. Finally the report closes with recommendations and conclusions, such as improving fire alarm signals and points about improving the waking effectiveness of fire alarms.

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CHAPTER 1. INTRODUCTION

1.1 Statement of Problem

The problem is that too many fatalities in fires are occurring while occupants are sleeping. Statistics have shown that the peak hours of home fire fatalities occurred between 1 am - 4 am. This is the time range when most people are in their deepest stage of sleep.

1.2 Scope

This report deals with finding improvements with waking effectiveness of alarms in New Zealand. Therefore, it shows that many detectors (or fire alarms) are not waking occupants during sleep and this report intends to find the answers to these questions.

1.3 Method

My report is based on an extensive literature research by reviewing the following:

- Sleep patterns
- Alarm characteristics
- Arousal response and problems from the alarms
- Human behaviour
- Review statistics from New Zealand, Australia and USA
- Consider solutions

1.4 Background

Firstly I look at the sleep characteristics which forms the basis of this report. Sleep patterns can be changed by a wide number of factors such as individual differences, age, gender, sleep deprivation and so on.

The experimental study of sleep can be dated back to 1862 when a student named Kohlshutter tested the auditory thresholds during sleep for one subject by using a sound pendulum. Similar experiments followed in the next 40 - 50 years. The major breakthrough was in the 1930's by a man named Kleitman who found that the initial rise of threshold occurred in the first hour of sleep (deep sleep) and then through out the rest of the night, the rate of threshold decreased.

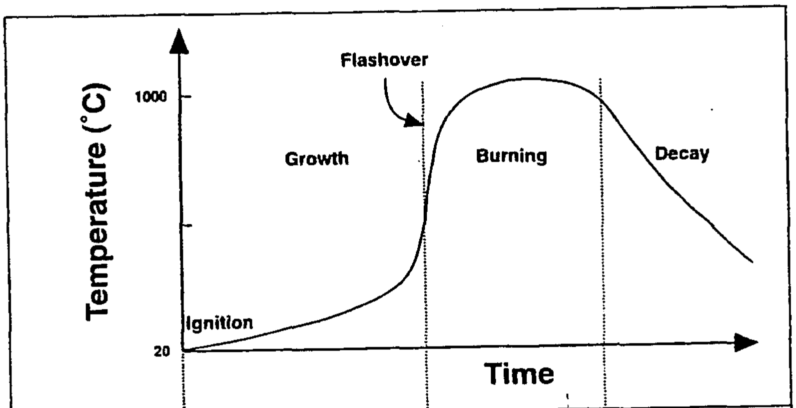
In 1937 the electroencephalogram (EEG) was first used as a measure of sleep behaviour by Blake and Gerard. The EEG was able to look at peoples sleep patterns, sleep cycles different stages of sleep and confirmed dream behaviour. The following years up to the present have resulted in extensive experimentation on threshold values and response to certain stimuli and a wide range of factors during sleep.

By researching information about sleep patterns I will be able to find a reason why humans react during sleep to fire cues. It has been shown by many experiments that the occupants may sleep through alarms because of many factors such as, background noises are too high, attenuation of sound due to location of alarm and construction material, sound may be incorporated into dreams or the occupant may not hear or recognise the alarm sound.

In the United States, 93 % of homes had at least one smoke detector (ie 13 of every 14 homes). It was shown that homes with detectors have a death rate of about 40 - 50 % less than the rate for homes without detectors. So people are still dying in fires even with smoke detectors, hopefully my investigations will show the reasons for this.

Tenable limits can occur in a very short time within minutes of a fire igniting in a home, therefore the occupant needs to respond quickly to a fire alarm by recognising it as a fire cue and to regain composure and take appropriate action ie. escaping.

The following graph shows a typical fire development curve, (Buchanan, 1994). As can be seen the first stage shows fire growth occurring at a slow rate depending on the combustible materials and the intervention from the growth stage to the burning stage is known as flashover where anything combustible in the fire area is burning.



Stage	Growth	Burning	Decay
Fire behaviour	Fuel controlled	Ventilation-controlled	Fuel-controlled
Human behaviour	Escape	Death	
Detection	Smoke detectors Heat detectors	External smoke and flame	
Active control	Extinguish by hand, sprinklers or Fire Service. Smoke control	Control by Fire Service	
Passive control	Flammability, surface spread of flame	Fire resistance, containment, collapse	

Fig 1.1: Fire development curve

If a sleeping person does not have a fire detection alarm such as a smoke detector installed they will decrease their chances of survival rapidly. The response time for a smoke detector can activate within 1 - 3 min from a fire igniting giving the occupant plenty of time to escape.

CHAPTER 2. SLEEP CHARACTERISTICS

2.1 General

In this section the background of sleep, sleep characteristics and sleep stages are measured also the sleep patterns are shown which vary with age and gender. Illustrations of sleep patterns are shown of the age groups with the highest fire fatality rates ie, 20 - 29 year olds and under 9 year olds and also the sleep pattern of the age group of 70 - 80 which has the lowest fire fatality rate. Comparisons were made of stage of sleep to fire deaths occurring in the first four hours of sleep.

Background material not referenced in this chapter were: Webb (1969, 1975), Okuma et al (1966), Ephron et al (1966), Dement et al (1957), Rechtschaffen et al (1968) and Davis (1976).

2.2 Assessment of sleep

To study sleep, various physiological variables need to be measured to aid in the investigation of sleep patterns. The most common means is by continuous recording of the electrical activity of the brain by using an electroencephalogram (EEG). To supplement the EEG identification additional information is required such as, recordings of the electro - oculogram (EOG) to measure the potential difference between the front and back of the eye, to detect vertical and horizontal eye movements (rapid eye movements, REM). The electromyogram (EMG) is also used to measure the muscle areas in the chin or neck as these muscles relax indicating REM sleep. Other methods such as continuous visual observation, interviews and questionnaires are occasionally employed

There are three behavioural sleeping states which include wakefulness (W), rapid eye movement sleep (REM) and non rapid eye movement sleep (NREM). NREM sleep physiology is summarised as 'a relatively inactive, yet actively regulated brain in a moveable body,' whereas REM sleep physiology is summarised as 'a highly activated brain in a paralysed body.'

The routine of sleep and waking behaviour is known as the sleep pattern. It has been established from research by Loomis, Harvey and Hobart then later by Dement and Kleitman that the sleep patterns are not uniform (steady state), but occur in various stages. These stages are Stage (W) waking, (NREM) stages 1, 2, 3, 4 and (REM) sleep stage.

From EEG recordings the stages can be shown by the following characteristics:

Stage W - is characterised by alpha activity and / or low voltage, mixed frequency EEG of 8 -12 Hz. Some subjects may show little or no alpha activity in the waking record. This stage may also be accompanied by a high tonic EMG, where REM and eye blinks may be present in the EOG recording. This is when the person is fully awake.

Stage 1 Sleep - a relatively low voltage, mixed frequency EEG with a prominence of activity in the 2 - 7 Hz range. A dominant mixture of low amplitude high frequency waves, and fast frequencies where alpha waves will tend to drop out and appear only intermittently. Stage 1 tends to range in duration from 1 to 7 mins. This stage is where the person is falling asleep and is in a transitional phase between waking and sleeping. People in this stage are easily awakened by noise.

Stage 2 Sleep - is identified by the presence of sleep spindles and / or K complexes. K complexes are defined as a negative sharp wave which is immediately followed by a positive component. Sleep spindles have more sharply pointed waves than alpha waves and of 12 - 14 Hz. These waves tend to occur in intermittent and frequent bursts over a low voltage background. This stage is the actual onset of sleep, stage 2 is a very important stage of sleep since its duration takes up more than half the total time spent sleeping. The person in this stage is sound asleep and easily awakened.

Stage 3 Sleep - this is a transient stage between stages 2 and 4 and is often combined with stage 4. It is characterised by at least 20 % but less than 50 % of high amplitude slow wave activity of 1 to 2 Hz, where sleep spindles may or may not occur. An intense noise is required to awaken the person.

Stage 4 Sleep - includes 50 % or more of high amplitude, slow wave activity. This is also described as the 'deepest' stage of sleep where sleep spindles may or may not occur. Stages 3 and 4 are usually described as slow wave sleep or delta sleep due to the similarities of both stages. This stage requires even more intense stimuli to waken a person.

Stage REM - is defined as a relatively low voltage, mixed frequency EEG activity and episodic REM. The EEG pattern resembles stage 1, except the vertex sharp waves are not prominent in stage REM. Sleep spindles and K complexes are absent from this stage. To help in measuring the REM stage, the EOG was used to reflect the presence of rapid eye movements where the EMG showed a sharp reduction in amplitude at the onset of stage REM. REM has been characterised by intense dreaming and rapid eye movements.

For normal adults about 50 % of total sleep is spent in stage 2, 20 % in stage 3 and 4, 25 % in REM sleep and 5 % in stage 1 and W sleep

The following graph shows the electroencephalogram (EEG) recordings of human sleep stages, (Horne, 1988). Wakefulness shows alpha activity (subject relaxed) and beta activity (alert). Theta activity can be seen in stage 1 sleep. Stage 2 sleep shows spindles and a K complex. Note the large slow waves (delta activity) of stage 4, also apparent to some extent in stage 3 sleep. Stages 3 and 4 together are 'slow wave sleep'. REM sleep stage is similar to awake and stage 1 with both theta and beta activity.

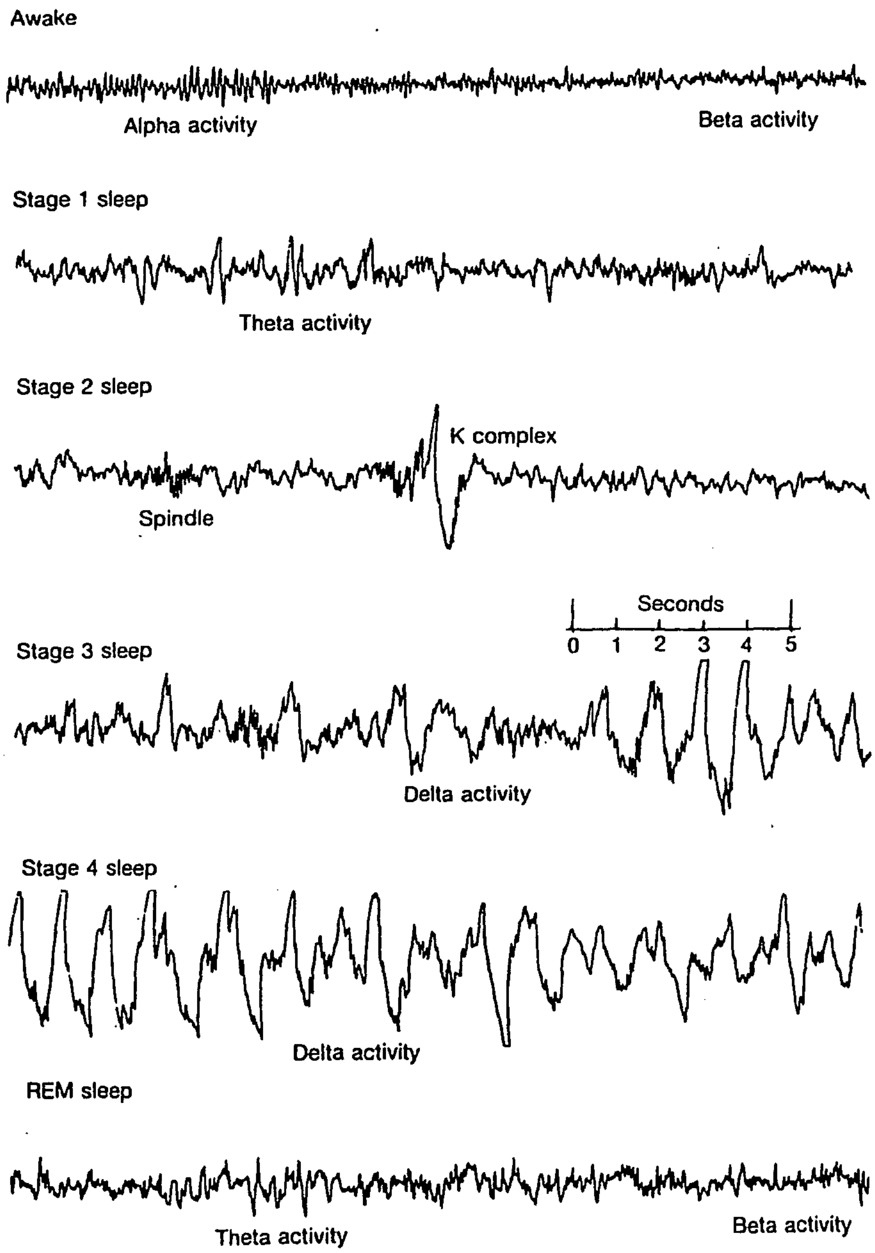


Figure 2.1: EEG of human sleep stages

2.3 Sleep patterns

The sleep stages vary in depth, where the depth of sleep becomes greater from stage 1 through to stage 4. The tendency for sleep stage changes is to follow an ordinal sequence; stage 1 to stage 4 and stage 4 to stage 1, where stage 4 is regarded as the deepest stage of sleep. REM typically emerges from stage 2 and occurs mainly in the second half of sleep.

An analogy from Webb (1972), imagine four rooms, one behind the other (Stages 1, 2, 3 and 4) with a front door to the first room (Stage 1) and no back door to the last room (Stage 4); off the room labelled 2 is a porch. This room is labelled REM.

Slow Wave Sleep (SWS), occurs predominantly in the first half of the sleep period and successive SWS periods become progressively shorter throughout the night. REM sleep is found predominantly in the second half of the night and successive REM periods becoming progressively longer throughout the night.

The sleep stages follow a fairly orderly cyclic pattern. REM occurs at regular intervals, where the EEG shows a regular and concomitant variation. These regular sequences of variation are called cycles. The first cycle is defined from the onset of sleep to the end of the first REM period. The second cycle is defined as the end of the first REM period to the end of the second REM period and so on. There are usually 5 to 6 cycles occurring throughout the sleep period, where each cycle has a duration of about 90 - 120 minutes.

After the onset of sleep, EEG recordings show that progress from stage W to stage 4 is quite a rapid progression and stays around stage 4 for about 30 minutes. Then an abrupt change takes place when stage 4 progresses back to stage 1 then into REM. After the first REM period ends the change from stage 1 to stage 3 or 4 takes place and persists for a time before going back abruptly to REM period. This cycle continues throughout the night.

The following graphs show the sleep patterns of three age groups, 20 - 29, (Horne, 1988) under 9 and 70 - 80 year olds, (Monk, 1991). Most fire fatalities occur in the first half of the night, (Chapter 7, figure 7.2). It was also shown that the age groups of the highest fatality rates were 20 - 29 and under 9 year olds, (Chapter 7, figure 7.4).

The 20 - 29 year old graph shows that there is a high amount of deep sleep in the first half of the night, which requires an intense noise to awaken from this stage. The under 9 year olds show that they have more deep sleep overall and basically they should not be left home alone. I included the graph showing the age group of 70 - 80 year olds, who had the lowest figure of fatalities in a fire. It shows that there is a disrupted sleep pattern, with continuous awakenings throughout the night, including a very low amount of stage 3 and 4 sleep.

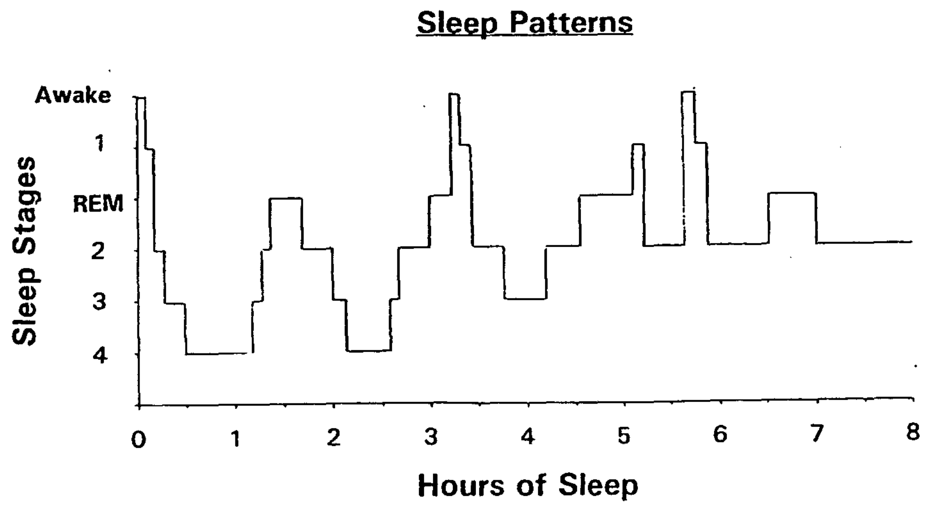


Fig 2.2: Sleep pattern of 20 - 29 year old age group

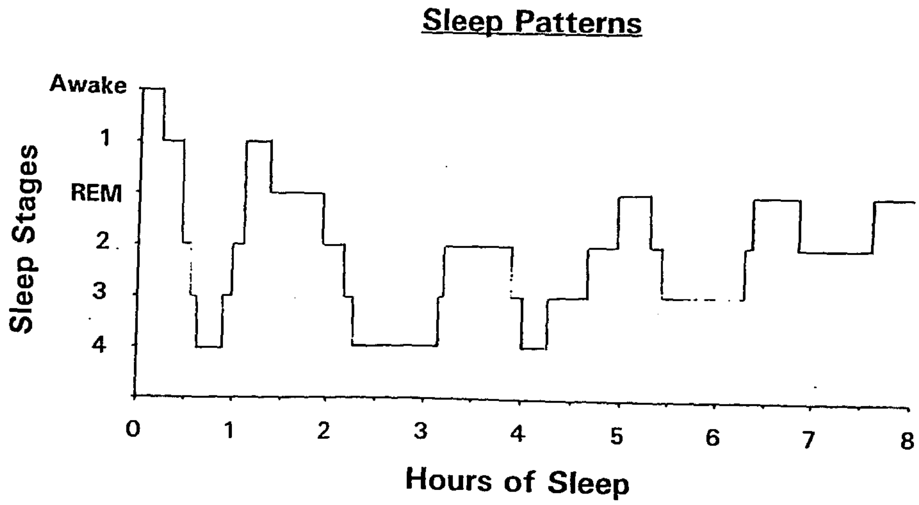


Fig 2.3: Sleep pattern of under 9 year olds

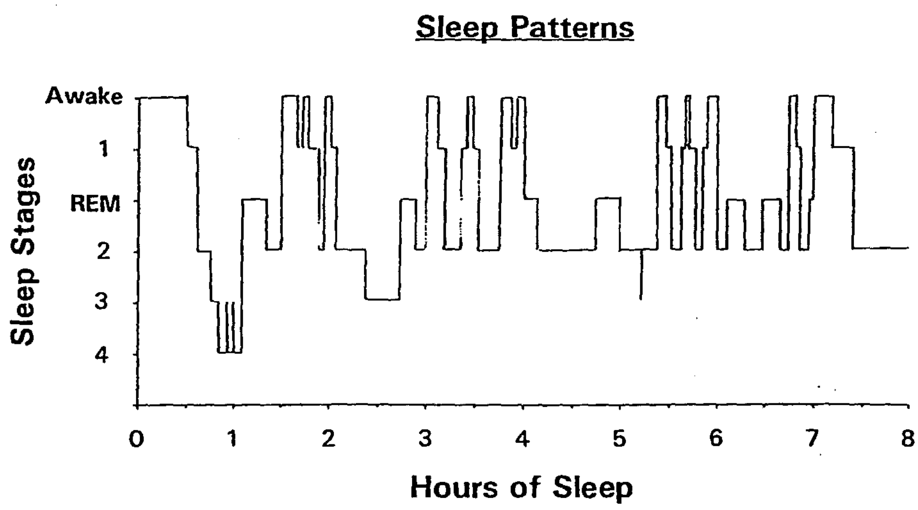


Fig 2.3: Sleep pattern of 70 - 80 year old age group

2.4 Gender and Age

Among 3 to 5 year olds total sleep time was greater for boys than for girls, as was the time spent in stage 2 sleep. Between the ages of 6 and 19, few sex differences in sleep profiles emerged. In the twenties, men experienced more nocturnal awakenings than did women and also less stage 2 sleep, and from the age of 40 onwards both total sleep time and the amount of REM were greater for women than for men.

Women also awoke less frequently and obtained more SWS. It was found that after the age of 30, fewer men than women were found to exhibit stage 4 and in the 70 year and above age group, stage 4 was completely absent in men, while being present in some women.

The total sleep time decreases with age especially between the ages of 3 - 12 and 12 - 20, but more marked in men than women. For sleep between the ages 6 - 16 years, the sleep duration declines from about 11 hours to 8 hours. Stage 1 - REM sleep, declines from about 30 percent to 25 percent by the age of 12.

It appears that there are two major age changes; Stage REM sleep increases from birth to a stable figure at abut 10 years of age; Stage 4 begins showing a rapid decline in the mid thirties which is also accompanied by an increase in stage W and stage 1 sleep. The amount of time spent in each sleep stage consistently and dramatically changes throughout life. Where SWS represents some 40 - 50 % of night sleep in infants this amount decreases to 15 - 20 % in adolescents, 10 - 15 % in the middle aged, and 0 - 5 % in the elderly. The percentage of REM sleep also decreases with age. The sleep of women is, in general, more resistant to age changes. One study found the sleep of 60 year old women essentially 10 years younger than the sleep of men of the same age.

The following graph shows the sleep duration of a wide range of age groups, (Colquhoun, 1972). It shows that NREM sleep is highest between the age groups of 5 months to 9 years, and this duration decreases with increasing age. It also shows that REM sleep decreases with increasing age.

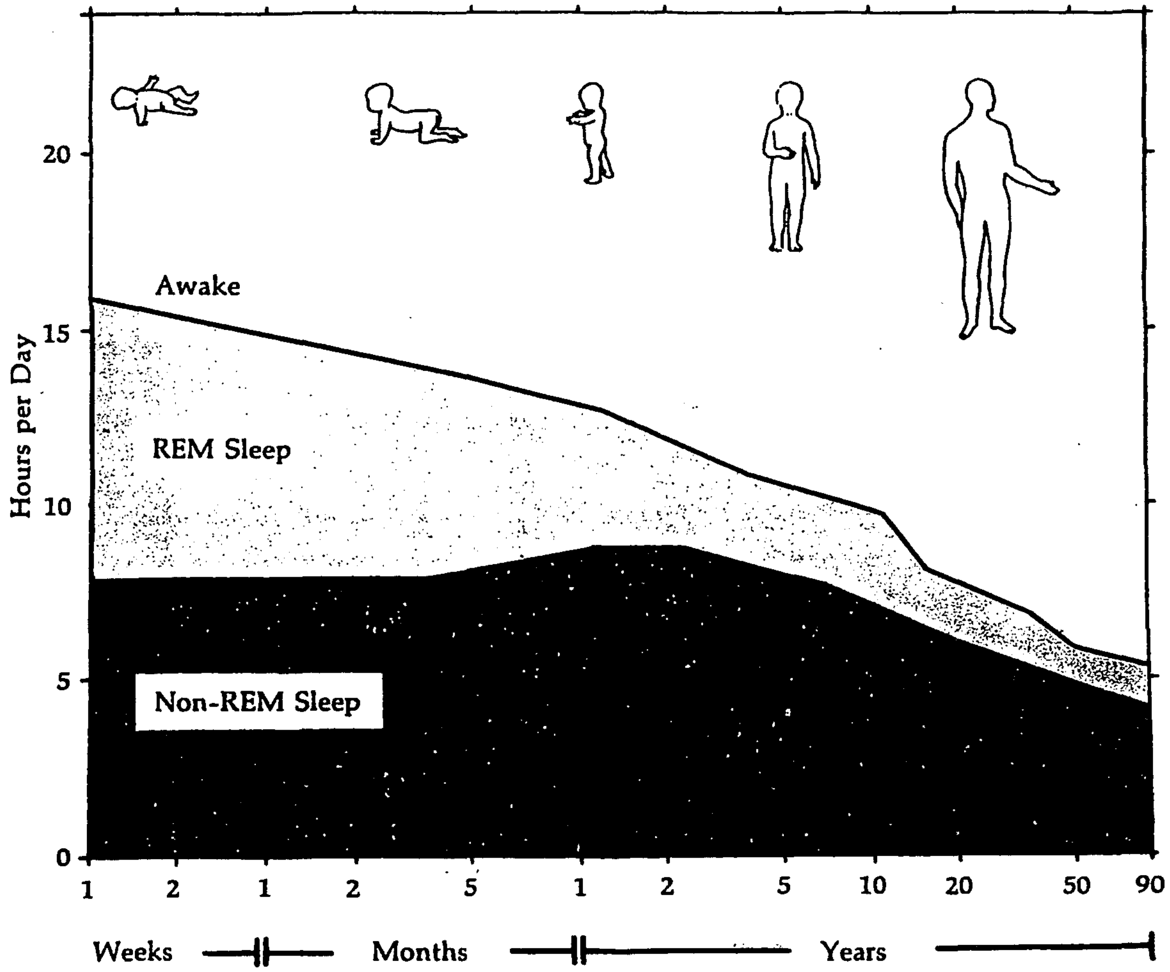


Fig 2.5 Duration of sleep stages with age

The significance of this graph is that young children should not be left home alone as they have the longest sleep duration, which includes the longest stage 3 and 4 sleep patterns, which makes it very difficult for them to awaken to an alarm.

CHAPTER 3. ALARM CHARACTERISTICS

3.1 General

This chapter begins with types of fire alarms available and then looks at the alarm intensities and frequencies. Following is an investigation of the types of fire alarm signals available and their problems. Finally voice fire alarms will be looked at, to see if this can be of any benefit.

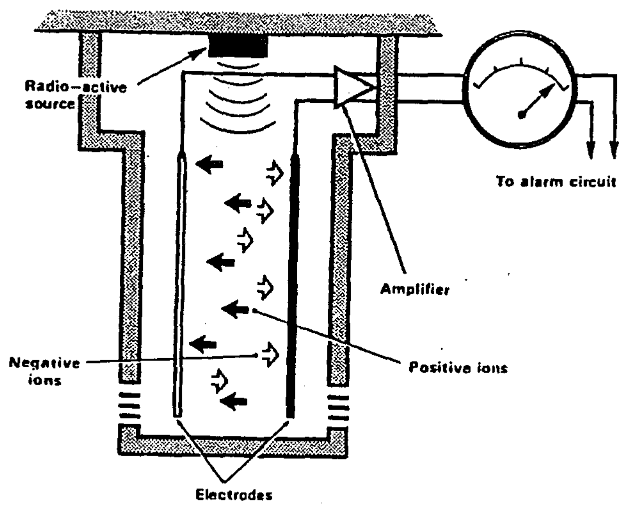
3.2 Types of Smoke Alarms

Smoke alarms monitor the air, detecting the smoke that enters the sensing chamber and thereby provides an early warning of potentially life threatening fires. When smoke is detected the unit will sound a built in alarm, and when interconnected to other smoke and heat alarms, all the units will automatically sound, alerting occupants throughout the building.

There are two types of smoke alarms currently in use for both commercial and domestic situations which are the Ionisation and Optical (photoelectric) detectors.

An ionisation chamber consists of two electrically charged electrodes and a radioactive source for ionising the air between the electrodes in order to carry a small current. As particles from combustion present in smoke enter the chamber, the ionised air molecules or ions attach to them, the current carrying capacity of the ions is then reduced, and this change is detected by the electronic circuitry and then the alarm sounds.

The following diagram shows an illustration of how the Ionisation chamber works.



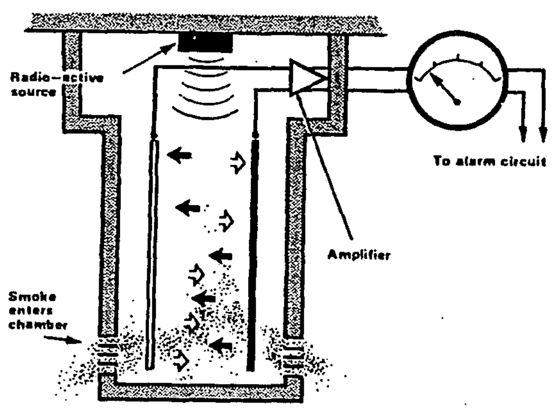


Fig 3.1: Ionisation chamber smoke detector

Domestic type optical smoke alarms operate on the light scatter principle. When smoke fills the light proof chamber the light from the infra - red beam is scattered or diffracted, so that it falls on a sensor (photo diode) that would not normally see the infra - red beam, and then will trigger the alarm.

The following diagram shows an illustration of how the Optical detector works

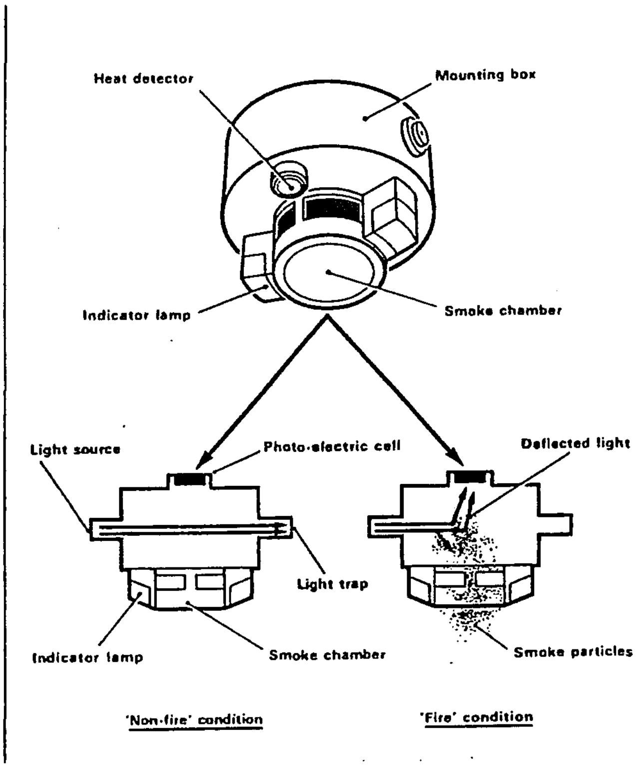


Fig 3.2: Optical detector

Ionisation smoke alarms are the most popular in domestic situations, mainly due to the fact that they are the least costly to produce. They respond to a very wide range of fires to be of general use and they are particularly responsive to fast flaming fires where little visible smoke may occur. But, ionisation alarms are vulnerable to irritating nuisance alarms caused by cooking, or portable gas heaters, which may lead to the alarm being disconnected. Furthermore ionisation alarms will be slower to respond to smoke produced by low smouldering fire.

Optical smoke alarms sense visible smoke particles, where again they respond to a wide range of fires to be of general use, but they are particularly responsive to smouldering fires and the dense smoke given off by foam filled furnishings or overheated PVC wiring. They are less prone to nuisance alarms from cooking and furthermore, contain no radioactive material. It is impossible to make the alarms dust proof, since they would then be smoke proof which defeats the purpose. That is why it is essential that optical smoke alarms are always kept clean.

The following diagram shows the optimum locations of smoke alarms in the home or residential area. As can be seen the best locations are the bedrooms so that the alarms have the best chance of awakening the occupant.

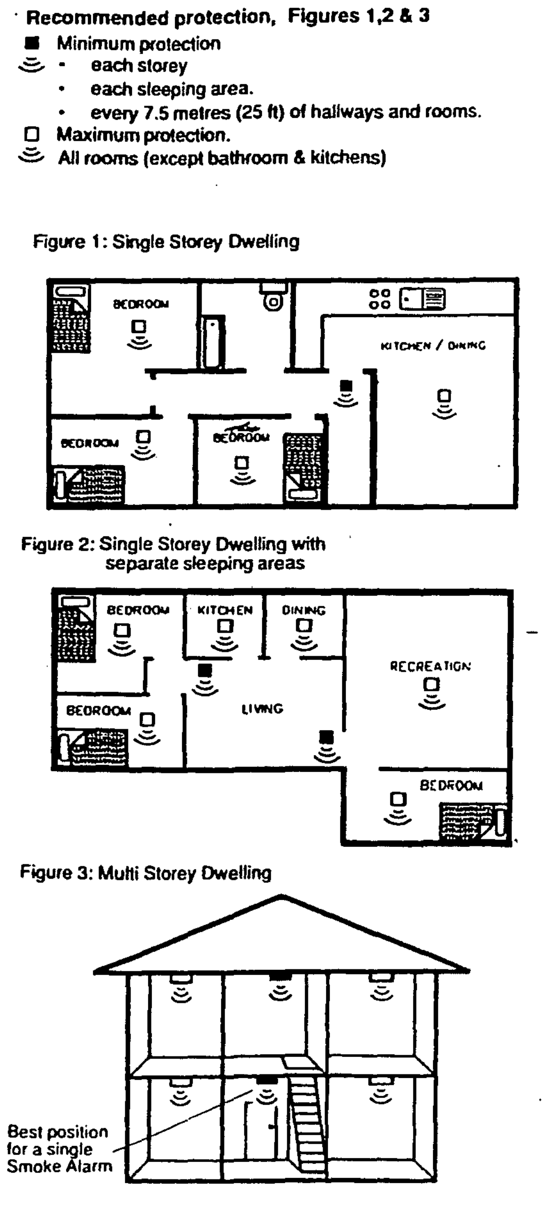


Fig 3.3: Recommended alarm locations

3.3 Alarm Intensities and Frequencies

LeVere et al (1973), showed that the lower frequencies had a better arousal rate than the higher frequencies. It appears that the frequency region between 750 and 1500 Hz are best suited as the region of maximum output for audible alarms. As of interest people over 60 years of age generally have difficulty perceiving frequencies higher than 10 000 Hz. Usually losses between 250 and 1500 Hz are less severe for all age groups, with progressively more severe losses in the region from 2000 and 8000 Hz. Spectral analysis showed that most smoke detector intensity / frequency spectral characteristics were relatively similar with bimodal energy peaks at 2000 Hz and 4000 Hz

(Nober et al, 1981 and 1983) The experiment assessed the intensity/frequency spectral characteristics of five popular household smoke alarm units sold in the USA. Sound level measurements (dBA) were taken in an anechoic chamber and reverberant room at 10 and 15 feet in a 360 degree directional polar axis and analysed as octave and 1/3 octave bands.

An assessment of the intensity - frequency spectral characteristics of the acoustic signal by smoke alarms were undertaken. The frequencies tested ranged from 63 Hz to 16000 Hz, with distances from the source to subject of 10 ft and 15 ft. The tests were conducted in an anechoic chamber and a reverberant room.

Spectral analysis showed the smoke detectors intensity/frequency spectral characteristics peaked near the 4000 Hz octave band and another cluster of energy occurred near the 2000 Hz band. This can be seen in the following diagram of a typical smoke detector.

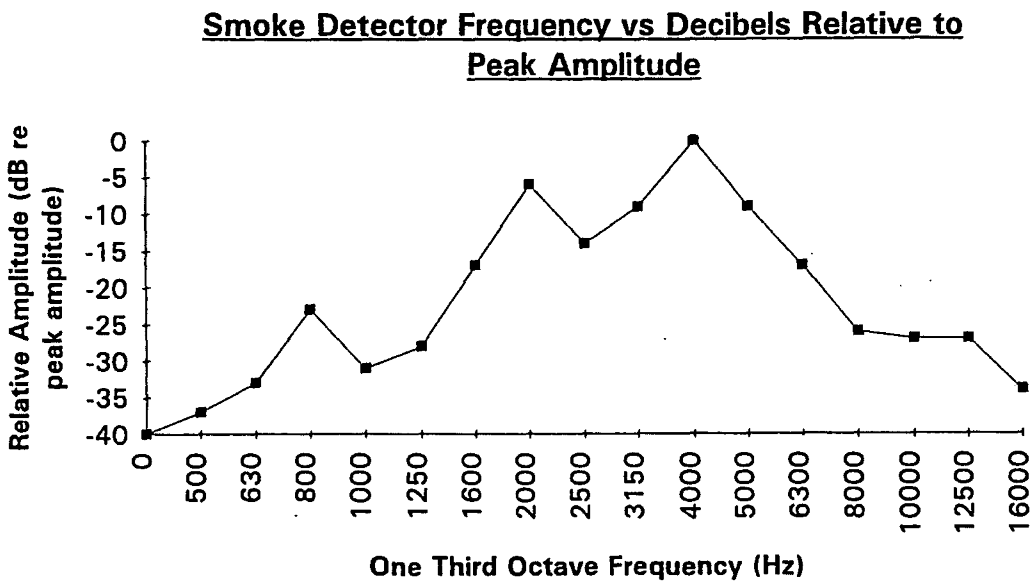


Fig 3.4: Smoke detector frequencies

The five smoke detector alarms tested showed that there were no significance between the distances to receiver (10 ft and 15 ft) and the sound intensity level. Measures from 10 feet showed a mean of 85 dBA (consistent with manufacturers claims) with a range from 80 - 92 dBA. At 15 feet, the mean was 81 dBA with a range from 74 - 87 dBA. Also the frequency levels of 63, 125 and 250 Hz were too low to be of any significance.

Comparison of spectral characteristics in the anechoic and reverberant rooms revealed somewhat greater intensity variability in the reverberant room. Furthermore, there was a great angle of incidence variance in peak energy (up to 10 dBA) in the anechoic chamber but only up to 3.5 dBA in the reverberant room. Thus data from the anechoic chamber representing 'peak value' and data from the reverberant room representing 'average value' were relatively comparable. Collectively these data should sample the extremes of possible household acoustic environments.

At any location within the signal reception area, the A - weighted sound pressure level of the audible alerting devices measured by a meter to BS 5969, with the time weighting "F" (fast) shall exceed by a minimum of 5 dB the noisiest background sound pressure level averaged over a period of 60 sec except that where voice facilities are used for evacuation purposes the sound pressure level shall exceed the noisiest sound pressure level by 10 dB. The sound pressure level of the audible signals shall not be less than 65 dBA and not more than 100 dBA. In buildings providing accommodation the minimum sound shall be 75 dBA at the bed - head with all doors closed.

3.4 Types of Fire Alarm Signals

The audible signal produced by the alerting devices shall be easily distinguishable against the ambient noise and shall be of a character distinguishable from other signals. Audible devices used throughout a system shall produce identical alerting signals.

The problem is that there are too many fire alarm signals in use at the present time. The following diagrams will show some of the fire alarm signals used at this present time, (Humphreys, 1973). All the fire alarms create confusion as to what is the difference between a fire, burglar, car or microwave oven alarm.

A common installation practise is to see what type of burglar alarm signal is used in a residential occupancy and then use a fire alarm with a different signal. Now this fire alarm signal installed in this building may be used as the burglar alarm signal next door, so its no wonder why people don't recognise fire alarm signals in their home.

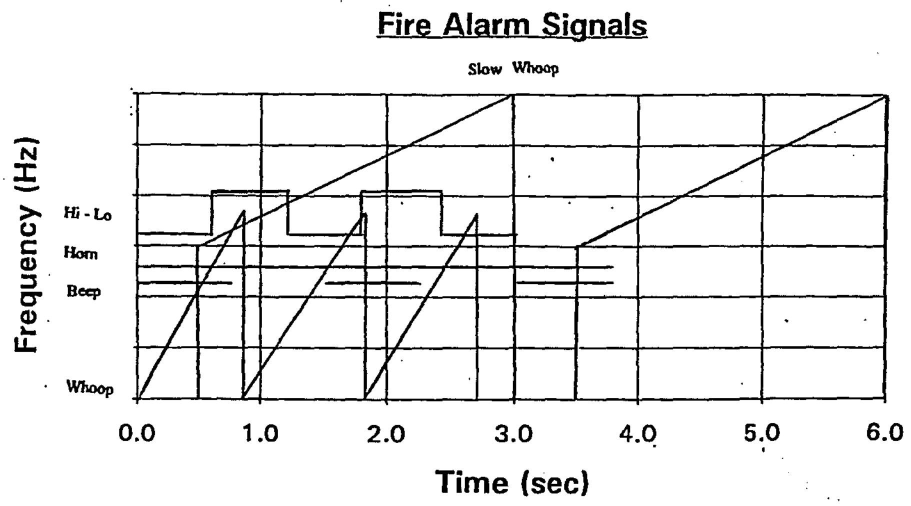


Fig 3.5: Fire alarm signals part 1

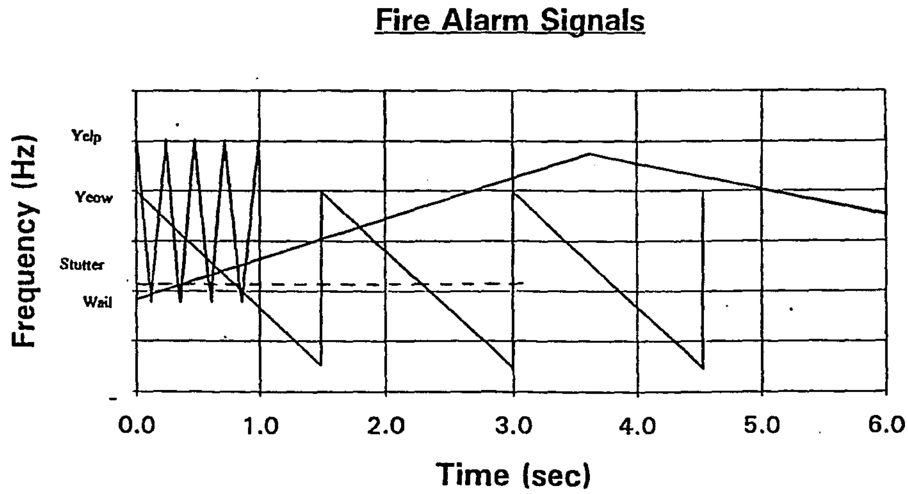


Fig 3.6: Fire alarm signals part 2

To alleviate the problem of too many fire alarm signal an international recognised audible emergency evacuation signal was made, (ISO, 1987). It was made so that the fire alarm signal could be universally recognised where a code 3 temporal pattern was to be used to combat the problem of too many different fire alarm signals.

It was shown that the fire alarm signal had to be universally recognised where a recommended code 3 temporal pattern will be used. An international recognised audible emergency evacuation signal was made. It was a temporal pattern 3 - pulse of 0.5 sec duration on, followed by 0.5 sec duration off. When the 3 - pulse signal ended, a duration of 1.5 sec occurred before the 3 - signal repeats again. There were various 3 - pulse signals: saw tooth tones, two tone, high low or low high sound and single stoke bell or chime.

(Humphreys, 1973) Several criteria were used in selecting the proposed fire alarm alerting signal:

1. Uniqueness. The signal shall not be in wide use at the present time, and it should be distinguishable from audible signals that are commonly used.

2. Practicality. The signal shall be producible by simple, low cost means within the present state of the art.

3. Exclusiveness. There shall be no legal or exclusive rights on use of the signal. It shall be non - proprietary

4. Generation. The signal shall be producible by various means - either electromechanically, pneumatically or electronically.

5. Loudness. The signal shall be capable of being produced to cover large, noisy areas as well as small, quiet areas.

6. Modulation. Since it is well recognised that people respond better to interrupted signals than to steady signals and that frequency modulated sounds are more easily distinguished from ambient noise than are constant frequency sounds, the signal shall be amplitude and frequency modulated.

7. Frequency. Since mid frequencies are less attenuated than high frequencies when passing through air or structures, since the average human ear is more sensitive to mid frequencies than to low or high frequencies, and since mid frequencies are easily transduced and transmitted over electrical transmission lines, the signal shall have considerable sound power in the mid frequency range.

The reason for the three - pulse temporal audible alarm signal was used to avoid possible confusion with other alarms and so the signal can be clearly distinguishable from other signals. Also the simple three pulse pattern would be used for alerting the deaf such as the use with visual and tactile devices and also used in connection with a telephone for alerting the guests.

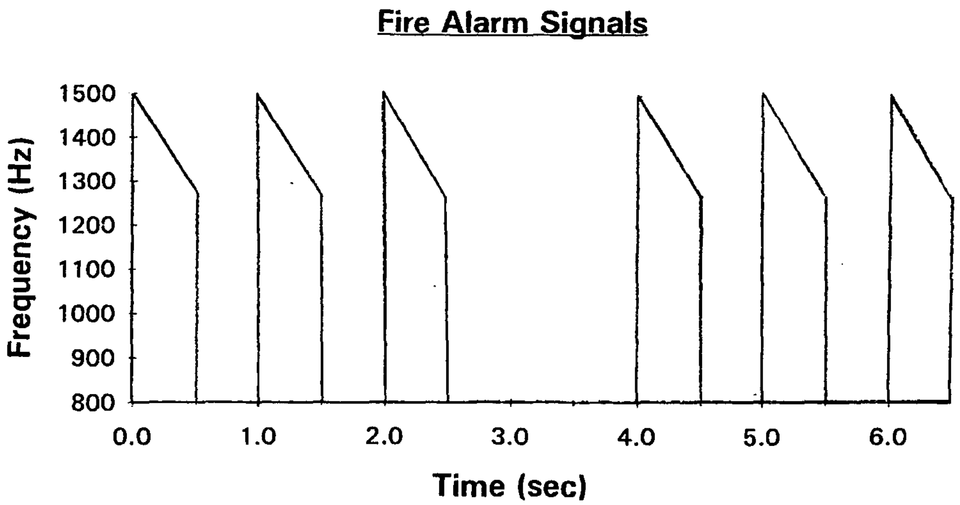


Fig 3.7: Three - pulse temporal fire alarm signal

3.5 Voice Fire Alarm Systems

(Hicks, 1994) The Early Voice Fire Alarm System (VFAS) was first used in USA, 1974. Most vocal emergency alarms today are used in public places such as hospitals, nursing homes and hotels.

Technological advancements have been made to create natural voice libraries giving end users more flexibility in which to convey their message. For example the system can call up a floor , wing or the entire building to deliver their message. This is because the building may be an enormous multi - storey complex, containing mixed occupancies where only some people need immediate evacuation and others need to be told to remain in the safe areas.

It was shown that the VFAS should:

- provide precise instructions for a variety of emergencies, eg bomb threat or fire,

- send various instructions to different areas of the building based on specific needs,

- include alerting sounds to get alert occupants and get their attention so the VFAS can deliver its message,

- include specific messages for a wide range of conditions,

- be able to modify and update information,

- include manual voice directions that can override or cancel all other messages.

Some factors which need to be assessed before placement of VFAS are that speech intelligibility needs to be considered where this will depend on sound levels, background noise and reverberation.

Speakers must be placed in areas of most effectiveness eg at door openings, where speakers must be in an area where people on both sides can understand the message. Masking of the VFAS due to auditory background noises may cause cancelling each other out, which is a problem.

Sound levels play a large part in VFAS where signal to noise ratios higher than 25 decibels are recommended. The design speech is most intelligible in range of 70 - 90 dB therefore more speakers are recommended instead of louder speakers. Frequency and pitch are also influencing factors where a female or male voice do differ in frequency and inflection.

Sound clarity is better in 8 - inch speakers than in 4 - inch speakers due to propagation of sound. A new method of testing the speech intelligibility of voice fire alarm systems being established. It is called the Rapid Speech Transmission Index (RASTI) and works by integrating signal level background noise and reverberation.

(Keating and Loftus, 1977)
The authors have shown that fire alarm messages are best used in hospitals and nursing facilities. To make an effective warning system for the delivery of an alarm message, the signal should possess the following characteristics:

1) Audible (heard above background noise)

2) Quick - acting (capable of evoking a quick reaction)

3) Alerting (catching peoples attention)

4) Discriminable (easy to differentiate from other signals)

5) Informative

6) Compatible (consistent with others in use)

7) Non - masking (not prone to interfere with other functions by drowning other audio signals)

8) Non - distracting (not startling)

9) Non - damaging (not cause irreversible damage)

The above characteristics should be satisfied in accordance that the sound levels of the system are to be at least 20 dB above background noises at 1000 Hz and it reiterates what Hicks has said.

The alerting emergency voice alarms in the health care facilities were coded to the staff, this was to hide from the patients that a fire alert was being sounded. The reasons were that in a general hospital that had intensive care patients as well as burn victims the disguised alerts were seen as exercising sensitivity towards such patients as well as their visitors. In nursing homes where between 50 and 70 % of the population was either immobile or not mentally alert, supervisors believed that confusion evoked by awareness that a fire was in the building would be detrimental to the safety of the patients and the staff. Similar reasons for disguising the message where given by supervisors in facilities that were treating mentally disturbed patients.

A sample message for an emergency fire situation was "Nurse Blaze, 4 West", this means that this message is targeted for the staff ie "Nurse". The code for a fire emergency is "Blaze", and the location of the fire is "4 West".

The main problem with this message is that it varies from one hospital to another, and staff moving from one to the other may get confused, so standardisation may be necessary or repeated training drills. Messages should not be too confusing where in a fire emergency the message said code red, but one doctor asked a nurse whether it was a code red for fire or cardiac arrest.

CHAPTER 4. EFFECTS OF AWAKENING DUE TO ALARM

4.1 General

The response to awakenings to the audible fire alarm sounds are investigated by looking at responses for different stages of sleep. Following is a look at how humans are able to discriminate between different sounds during sleep. Finally solutions such as motivation and training are shown, that could increase the awakenings to alarms while people were sleeping.

4.2 Response to Auditory Alarms During Sleep

From EEG responses to auditory stimulation, it was shown that the percentage of subjects responding to auditory stimuli decreased as they went through the stages of sleep from stage 1 to stage 4, (Rechtschaffen et al 1966). EEG response to auditory stimulation was related to the depth of sleep and to the ambient noise level in the room. Observations were made of the EEG response to auditory stimulation to arousal from sleep and the ability to discriminate between auditory stimuli at various stages of sleep. Responses from stage 1 require less stimulation than from stage 4.

In response to a standard signal, there is a negative relationship between the intensity of the signal required to obtain a response and sleep stages 1, 2, 3, and 4 in that order. Responses from stage 1 require less stimulation than from stage 4, where low intensities may not wake a person up but loud noises will.

It appears that awakening threshold is similar for REM periods and stage , but both have lower awakening thresholds than delta sleep, (LeVere et al, 1973). Results of his experiments indicate that auditory stimuli are adequate stimuli in terms of arousing sleeping individuals.

Observations were made of the relationship of content of auditory stimulation to arousal from sleep at the various stages of sleep, (Zung et al, 1966a). Responses to auditory stimulation by 15 normal sleeping males indicate that when they were in the sleep stages 1, 2 and 3 stages of sleep response to auditory stimulation was 7, 5.5 and 4 times more frequent respectively, compared with the stage 4 of sleep. This can be seen in the following graph.

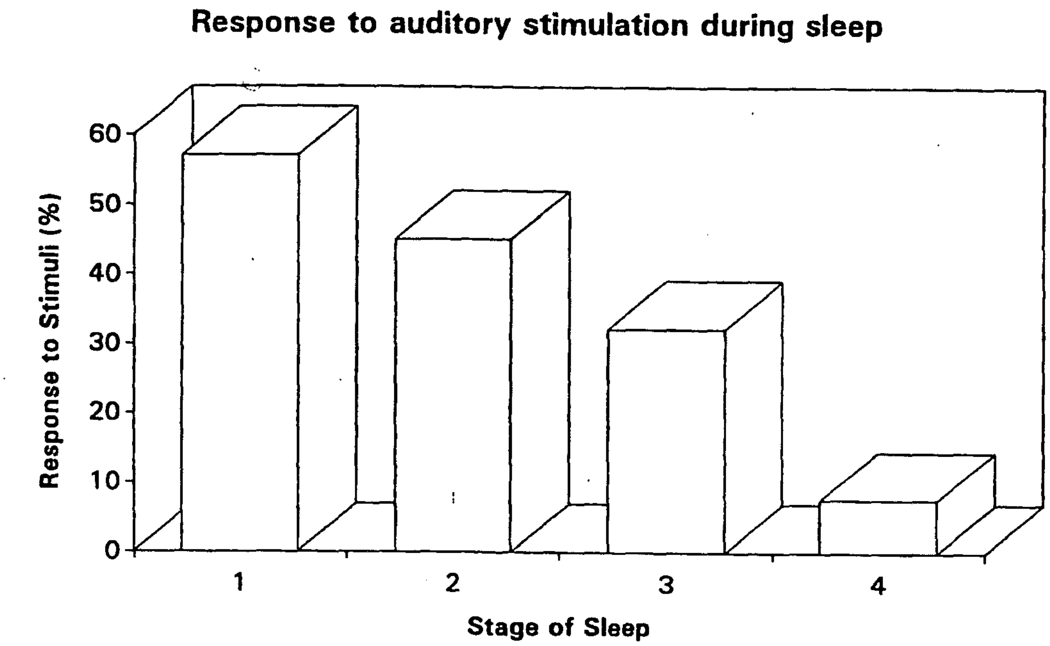


Fig 4.1: Response to auditory stimuli

The results show that the percentage responded to auditory stimulation according to the various stages of sleep are Stage 1 - 57.1 %, Stage 2 - 45.1 %, Stage 3 - 32.2 % and Stage 4 - 7.6 %. As can be seen from the above graph, the SWS is the hardest to awaken from in sleep.

Men in there twenties experienced more nocturnal awakenings than did women and also less stage 2 sleep. It was found that after the age of 30, fewer men than women were found to exhibit stage 4 and from the age of 40 onwards both total sleep time and the amount of REM were greater for women than for men. Women also awoke less frequently and obtained more slow wave sleep. and in the 70 year and above stage 4 was completely absent in men, while being present in some women. The sleep of women is, in general, more resistant to age changes. One study found the sleep of 60 year old women essentially 10 years younger than the sleep of men of the same age.

Older people awaken faster, have less stage 3 and stage 4 and have an increase in latency to sleep onset and increased spontaneous awakening. Hence a greater frequency of arousal with advancing age. The elderly have shorter 'grogginess' periods after arousal, become alert faster when aroused from sleep and are easier to arouse from all stages.

The question as to which stage of sleep is the deepest is determined by the awakening threshold. Many variables are associated with the awakening threshold namely; stimulus intensity, sleep stage, subject differences, accumulated sleep time, amount of prior sleep deprivation and past experience with the stimulus.

The average auditory awakening threshold (AAT) was about 65 dBA. Comparisons of sleep stages with auditory awakening thresholds were made where the delta sleep (stages 3 and 4) had the highest awakening thresholds. Awakenings were more frequent in stage 2 sleep and were similar to REM sleep. The accumulated sleep caused lower awakening thresholds in all stages of sleep. Awakening thresholds became lower with accumulated sleep, independent of sleep stage.

4.3 Discrimination Responses

The arousal response of certain sounds will be significant such as a mother awakening to the sound of her child but will not awaken in a thunder storm.

Subjects in a study by Kahn (1983) were unable to identify smoke alarm sounds despite that many had heard alarms before. It was likely that the subjects had trained themselves in reacting to an alarm sound by battery testing and accidental activation by cooking. But when awakened by a different alarm sound, the stimulus was unfamiliar, training was lost and the subject was not able to identify the alarm as a fire warning.

Experiments of response from subjects during sleep were recorded. The subjects were asked to respond to their names or a name given to them by clenching their fists during sleep. The names were spoken at a set intensity by tape recorder. Results showed that hand movements were significant when hearing the names. The EEG showed significant K - complexes when subjects heard names including responses by galvanic skin response (GSR). Therefore it was shown that sleeping subjects can discriminate between auditory stimuli.

It is general knowledge that people can discriminate between auditory stimuli while asleep, (Zung et al, 1966b). The use of electroencephalography had been used to show the ability of a sleeper to discriminate auditory stimulation, by the EEG changes in response to auditory stimulation. Also EEG response to auditory stimulation was related to depth of sleep and to the ambient noise level in the room. The experiment showed that the responses depended on the content on the sound rather than on its intensity.

Pre - taped recording of various sounds, which would be familiar or unfamiliar to the sleeping subject were played. Familiar sounds included cars starting and stopping, bagpipes playing and gun shots. All sounds played were of the same approximate intensity as measured in decibels.

Other experiments have used names as a basis for discrimination during sleep, (Oswald, Taylor and Treisman, 1960). Where some words (a subjects name for example) hold more relevance for the subject than others and, thus, could be termed signal stimuli. They had found that subjects responded more often (hand clasp response) to their own names than other names. The production of a K - complex response to the names was also scored. A K - complex was significantly more likely to follow the presentation of the subjects name than other names.

4.4 Motivational Responses

The EEG responses also showed that the percentage responded for motivated subjects were very high for all stages of sleep, (Zung et al, 1966). As the sleep stages increased for the motivated subjects, their percentage responded also increased, where 100% responded in the deep stages of sleep namely 3 and 4. An example of motivation responsiveness is where certain sounds will be significant such as a mother awakening to the sound of her child.

Therefore it shows that simple experimental instructions could greatly influence responsiveness during sleep and that people were capable of making significant modifications of their responsiveness during sleep.

There were no significant differences of response to familiar and unfamiliar sounds in each of the stages of sleep. Some subjects were motivated (rewarded by extra pay) to waking up to specific sounds eg bagpipes playing and phone ringing.

For motivated and neutral subjects, stages 1, 2, and 3 showed that there was a significant difference but in stage 4 there was none. But further analysis showed that comparing response to motivated subjects and control group, it was shown that their were significant response differences for stages 2, 3 and 4 but not stage 2.

Although a person does not discriminate between familiar and unfamiliar sounds at any sleep stages, he/she can and does discriminate between sounds in all stages of sleep when motivated. The specificity of the discriminatory ability of the sleeping person can be further seen when one can discriminate the motivated stimulus of a telephone ringing from those neutral stimuli such as the door bell ringing, chimes and clock striking, which are all very similar in their sound.

Therefore normal sleeping subjects, who had been previously motivated to discriminate auditory stimuli, were able to make this discrimination in all stages of sleep, the people waking up more frequently to the motivating auditory stimuli.

The arousal responses between men and women for neutral auditory stimuli during sleep stages 1, 2, 3 and 4 showed that there was a significant difference when more women responded than men. But there was no significant differences in the REM stage. Arousal threshold differences between male and female subjects were for insignificant auditory stimuli but, females had a lower threshold and therefore a higher responsivety

In comparing the ability of men and women for responses to motivating auditory stimuli it showed that there were no significant differences.

The following graph shows results which indicate that when sleeping,male and female subjects were presented sounds which have meaning and are motivating, the overall arousal pattern is significantly different from that when neutral non - motivating sounds are perceived.

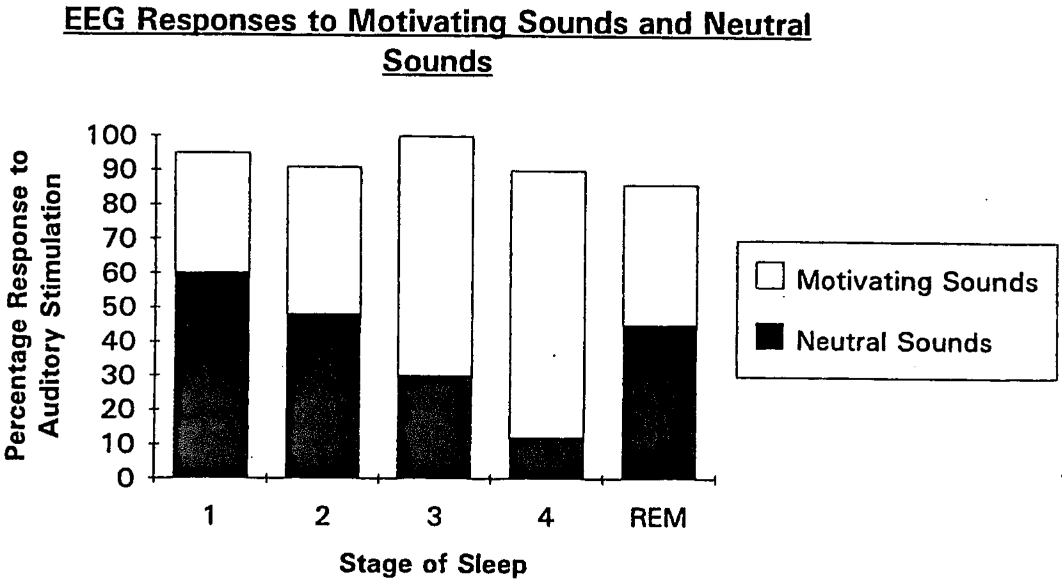


Fig 4.2: Motivating vs neutral sounds

Arousal to auditory stimulation during sleep is dependent upon its affective content. Sounds which are emotionally laden and important fire cues which evoke more response than the sleeper than sounds that have little or no emotional content. For example, the phenomena of mothers waking up to the cry of infants, or the arousal to telephone ringing to doctors on call. A 'significant' auditory stimulus could also be thought of in terms of a cessation of sound, where previously there was continuous or background auditory stimulation. Where the offset of a particular sound with its silence has become the meaningful sensory signal eg, a person who is in the habit of sleeping with a room air - conditioner on, wakes up during the night when it suddenly goes off.

People can discriminate between complex stimuli by awakening from sleep to a certain stimulus. By responding to the sound of a telephone ringing, one can discriminate it from other similar sounds such as, a door bell ringing, or a clock striking.

In a study by Kahn (1983) many people were unable to identify smoke alarm sounds despite that many had heard alarms before. But when awakened by a different alarm sound:

- the sound was unfamiliar,

- training was lost

- they were not able to identify the alarm as a fire warning.

In another experiment subjects were told that either an 800 or 1200 Hz tone was a 'critical' tone and the other was not. Under one condition. non - response to the critical tone was punished by a fire alarm, flashing light and threat of shock. Subjects displayed an ability to push a microswitch proportionally better to the critical tone than to the neutral tone in stages 1, 2 and REM, with the best discrimination seen in stage 1. Response to the neutral tone was uniformly low (20%) in all stages under all conditions, while responses to the critical tone averaged about 70% across all conditions in stage 1, 30% in stage 2 and 35% in REM. Response rate in stages 3 and 4 was very low in all conditions.

It had been clearly demonstrated that sleeping subjects can make complex discriminations between repetitive auditory stimuli where they can for instance, discriminate between meaningful words such as the subjects name, (LeVere et al, 1976).

Therefore it has been confirmed of the belief, that a person can set themselves the task of awakening to some particular stimulus and can in fact, succeed in that task to some extent.

4.5 Waking Effectiveness to Fire Alarms

(Nober et al, 1983) The experiments were about subject response to smoke detector alarm signals for actual experiments in the subjects home

Three experiments were used to test the response times of motivated subjects for three smoke detector alarms of 55, 70 and 85 dBA for waking effectiveness using young adults aged between 19 and 29 years of age. The response times started from alarm activation to switching off the alarm and / or telephoning the fire department.

The shut off latency's measured from when the alarm went on to when the subject shut off the alarm were 13.6 sec, 9.5 sec and 7.4 sec for the 55, 70 and 85 dBA respectively. Mean response to telephoning the fire department was 70 sec, 61.6 sec and 53.6 sec respectively.

It is clear that the rapid subject responses represent performance by a motivated population of young adult volunteers. While the test environment was field - based at the subject's home, the subtle implications of the instructions, the visual and physical presence of the apparatus, the expectation of an alarm to be activated and a self driven desire to respond well may have influenced the subjects to yield this high level of performance.

The first experiment was the response times for the alarm signal only. It was shown that the 85 dBA caused the fastest response times but 70 dBA had similar response times for the experiments.

Experiment two assessed the waking effectiveness of the detector alarm signal in the presence of an air - conditioner noise background of 53 dBA.

All subjects received the alarm signal of 55 and 70 dBA near 3.30 am.
Response times for the 55 dBA sound was very slow where some subjects did not wake up at all.

Three subjects did not wake up where the mean waking response latency for the 55 dBA alarm was 43.4 sec where the signal to noise ratio was 4.2 dBA.. For the 70 dBA alarm the latency for the waking response was 18.8 sec where the signal to noise ratio was 21 dBA. Therefore subjects respond faster when the signal to noise ratio was 21 dBA than 4.2 dBA.

As of interest the fast response subjects consistently normally awakening an average of one time per night as a regular pattern while the slow response subjects never or rarely awakened throughout the night. The subjects with no response averaged 90 mins into sleep when the alarm was activated whereas the faster response subjects averaged about 200 mins into sleep, which means that the latter went to sleep earlier.

Therefore the no response subjects with only 1.5 hours into sleep was consistent with the previous literature which reported greater resistance to arousal from sleep during this period of 3:30 am.

The last experiment involved the response times of three populations (normal households, geriatric households and mentally retarded groups) to a smoke detector alarm. The response times were measured from alarm activation to last person leaving the final exit.

It was shown that evacuation times for the elderly and retarded groups were significantly longer than normal households. The normal household with or without children had a response time of 48 sec, whereas the elderly was 67 sec and mentally retarded was 58 sec, so the response times were very good. This shows that households can be totally evacuated in one minute from alarm activation during sleep. These faster response times including evacuation shows that discrimination to the alarm signal and motivation to awaken due to wanting to perform well for the experiment.

Two experiments were undertaken by Proulx et al, (1995), the first involved the evacuation and behaviour of residents from four apartment buildings. The occupants included a wide range of people such as children, adults, seniors and disabled people.

It was shown that building 1 had the shortest time delay of 2.3 min, where each bedroom had its own fire alarm speaker whereas the other buildings only had alarms in corridors and staircases. The average time delays were 8.22 min and 9.42 min, where 25 % of the occupants did not hear the alarm. The last buildings average time delay was 3.08 min where 17% of the occupants did not hear the alarm.

The second experiment involved three buildings where the alarms were located in various areas of the apartments. It was that with or without alarm bells the overall sound pressure levels were almost identical except for the corridor where 94 dBA was recorded.

Results were obtained for the comparison of frequency and dB SPL by a software package called Detect Sound™. It was shown that the fire alarm had a low audibility whereas the corridor was too loud. The alarm signal was affected by the background noise. Many occupants did not hear the alarm, so if they were sleeping it could have been worse.

(Bruck et al, 1993) The aim of this experiment was to find out how reliably a smoke detector alarm when activated at a level found in a typical installation in residential homes would awaken a normal sleeper when not trained to expect the signal.

Field work showed that the type of alarm commonly used in households was a standard smoke detector on sale in Australia. It could emit a sound level of 85 dBA, with an average sound level of 60 dBA at the pillow.

The alarm was presented for a maximum time of 10 mins uninterrupted, and if the person was still asleep the alarm was presented again. All stages of sleep were assessed, where alarm activation for stage 4 was in the first third of the night, stage 2 in second third and REM stage in the last third of the night.

It was found that five out of 24 subjects were not aroused by one or more presentations of the alarm. It was shown that one person could not awaken to the alarm in stage 3 and 4 sleep, even when the alarm was repeated six times. The other people slept through the alarm when presented in the REM sleep stage (which may be attributed to incorporation of the alarm into dreams) and two cases where a person slept in stage 2 during the alarm.

The following graph shows the times that were taken from activation of the alarm to a person regaining full EEG wakefulness. Data from the experiment showed that the mean latencies for awakenings were longer and more variable in stage 4 sleep than in stage 2 or REM sleep. It was shown that 23 % of the awakenings from stage 4 sleep had a latency longer than two minutes, while all other awakenings were within two minutes.

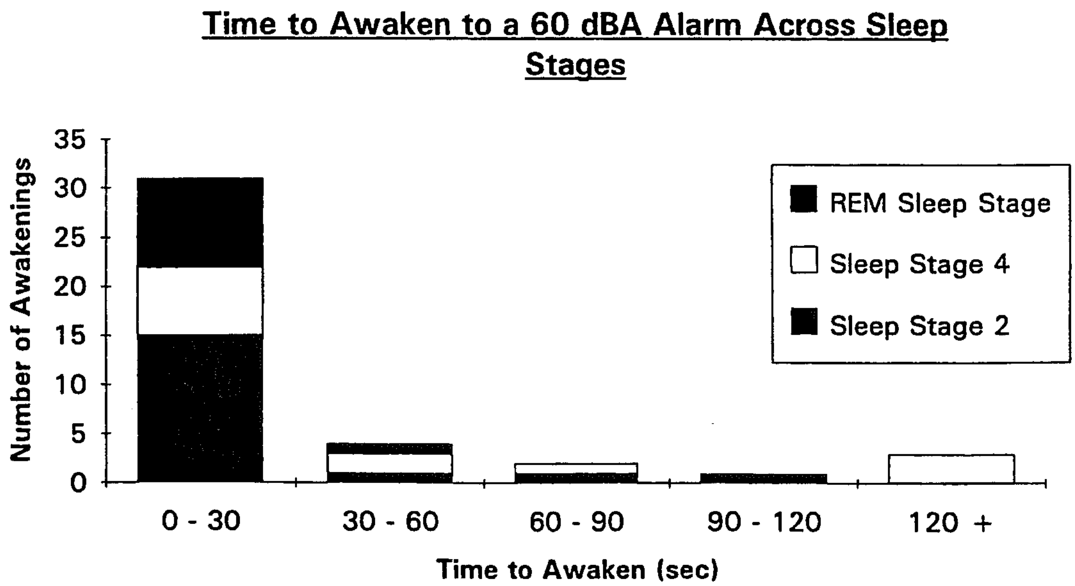


Fig 4.3: Times to awaken at different sleep stages

4.6 Response to Different Auditory Frequencies

The arousal produced by auditory stimuli is affected by varying its auditory frequency.

An alarm of 80 dBA with a 45 dBA background noise, was trialed with various frequencies of 125, 250 and 1000 Hz, (LeVere et al, 1973). The experiments were made to see if the subjects response was similar to sleep as it was during waking. The comparisons were made between fast waves and slow wave patterns recorded by an EEG.

It was shown that for fast wave sleep, the different frequencies were all effective in arousing the subjects. But the slow wave sleep showed that that arousal rate was faster than the fast waves.

The following graphs shows that during SWS, the participants arousal effectiveness has a faster rate than the sleep stages 1 and 2. Also it can be seen that the lower frequencies have a better arousal rate than the higher frequencies, but the problem with the lower frequencies is that it needs more intensity in loudness to have an equal sound intensity as the other higher frequencies.

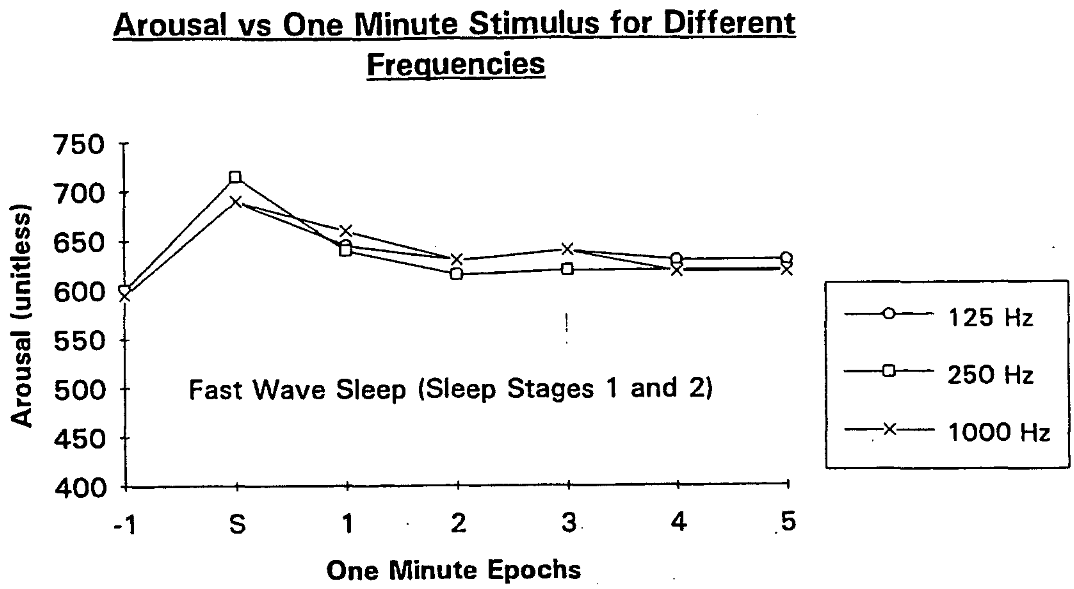


Fig 4.4: Arousal rate for fast wave sleep

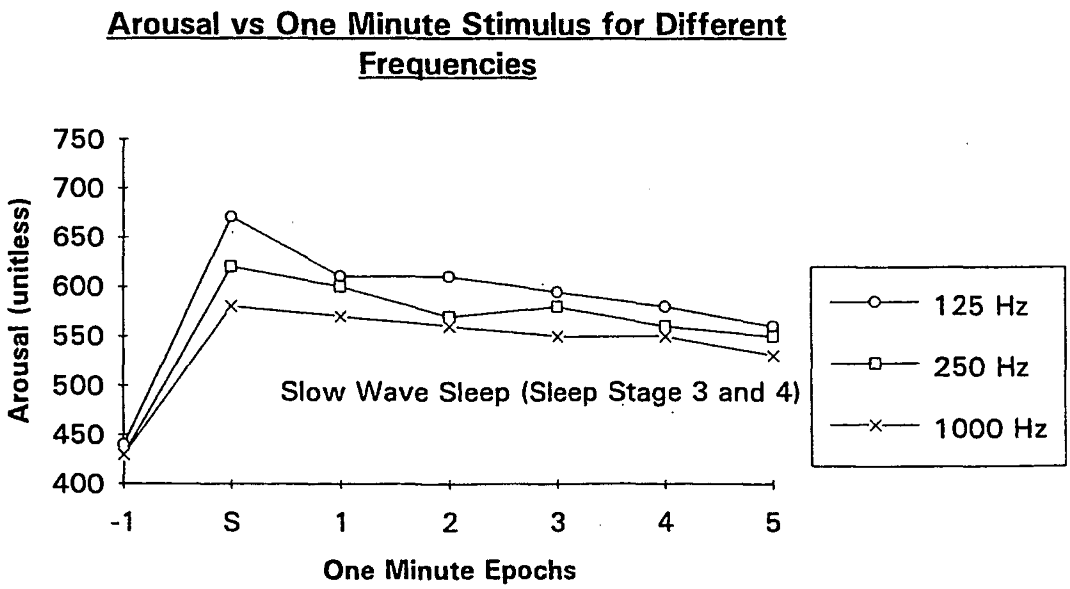


Fig 4.5: Arousal rate for slow wave sleep

Lower frequency stimuli must be physically more intense to be judged equal in loudness to higher frequency stimuli, (LeVere et al, 1974). The following graph shows the average sound pressure level (SPL) which was required to make the 50 Hz stimulus and the 250 Hz stimulus equally loud to the reference 1000 Hz stimulus.

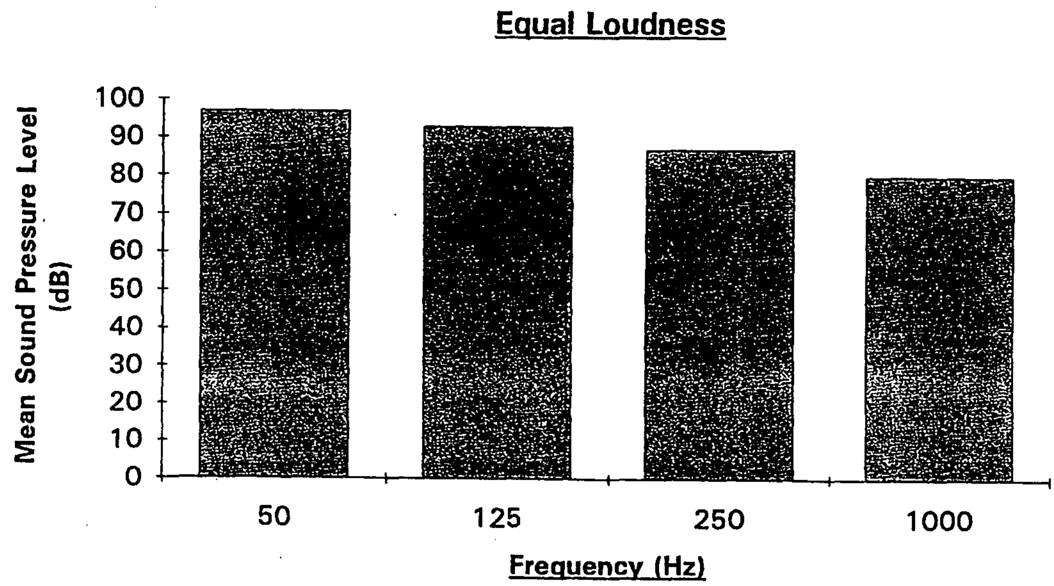


Fig 4.6: Different frequencies equated for equal loudness

CHAPTER 5. FACTORS AFFECTING AWAKENINGS

5.1 General

In this chapter the problems of awakenings such as the detrimental effects that drugs and alcohol have on the sleep patterns are shown, including the problems of alarm frequencies and how these characteristics affects certain age groups. Sleep deprivation is an area of concern where responses to fire alarms are looked at. Then a look into alarm incorporation into dreams and how this could affect awakenings. Finally the effects of alarms in building layouts and the responses to various fire related cues are shown.

5.2 Effects of Drugs and Alcohol

The response of subjects under the effects of a drug called Triazolam to the smoke detector alarm were tested, (Johnson et al, 1987). The dose levels were 0.25 mg and 0.50 mg, where placebo was used as well. The alarm was 78 dBA with a 32-34 dBA background noise It was shown that all the placebo subjects were awakened by the alarm signal. Whereas 50% of the subjects affected by Triazolam did not awaken on the first alarm signal.

The response times of subjects during the second stage of sleep was longest for the 0.50 mg of dosage, the slow wave sleep showed both 0.25 mg and 0.50 mg had very slow reaction times. The second night showed that all response times had decreased but the arousal levels for the Triazolam users were still higher than the placebo users.

Alcohol reduces sleep latency and improves sleep continuity in low concentrations such as a pint of beer or a glass of wine, (Monk, 1991). But excessive intake of alcohol will have more significant effects on the sleep patterns.

The following graph shows that SWS amounts increases in the first half of the night with REM sleep decreasing. The second half of the night shows that SWS becomes non - existent where REM sleep and stage 2 sleep dominated. Also there were more awakenings in the second half of the night.

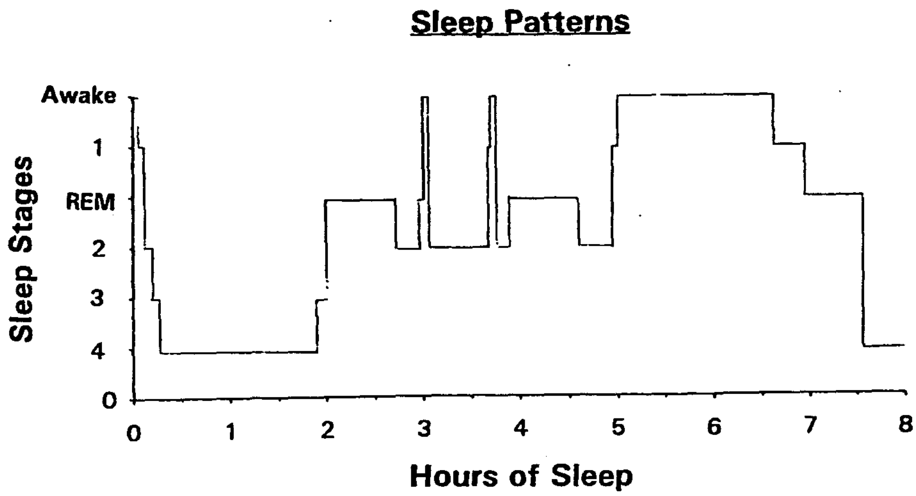


Fig 5.1: Sleep pattern after alcohol intake

The increase in wakefulness and SWS and decreases in REM sleep and sleep latency due to alcohol are all dose - related, ie the more drinks one has the more effect it has on the sleep patterns. Alcohol does indeed impair performance such as reaction time to an alarm or motor coordination and problem solving upon awakening.

Gender, age and using other drugs are factors which will change sleep patterns and awakenings. Increasing age increases performance impairment with alcohol where use of other drugs with alcohol will cause more SWS with the result ending in a coma. As a matter of fact women have a greater performance impairment than men.

Following is a table of drugs and their effect on sleep and performance.

Drug	**Pharmacological Properties**	**Effects on Sleep**	**Effects on Performance**
Clonidine	Rapid, complete absorption	SWS increases Wakefulness increases Stage 2 increases REM Sleep decreases	Subjective reports of mental slowing, impaired mental acuity
L - Dopa	Rapid absorption	SWS increases REM Sleep decreases	Improves sleep in Parkinsons patients
Anti - psychotics	Oral absorption unpredictable	Depth of sleep increases SWS and REM Sleep increases Wakefulness decreases	Motor performance decreases Attention decreases
Anti - cholinergic agents	Rapid absorption given intravenously	SWS increases REM Sleep decreases Sleep continuity disturbed	Psychomotor and memory impairment in young and elderly subjects
L - Tryptophan	Well absorbed, incorporated into proteins	SWS increases REM increases	No data
Barbiturates	Well absorbed	Wakefulness decreases SWS remains the same REM decreases Sleep length decreases	Impaired attention, vigilance, judgement and motor skills

Aspirin	Rapid absorption Wide distribution	SWS decreases REM Sleep decreases Wakefulness increases	Impaired concentration, perception, coordination, learning and memory
Lithium	Completely absorbed Wide distribution	SWS increases REM Sleep decreases Wakefulness decreases	Performance decreases and minor memory impairment
Phenytoin	Slow absorption Wide distribution	SWS increases REM Sleep decreases Sleep latency decreases	No data
Zopiclone	Rapidly absorbed Widely distributed	Improved sleep quality SWS increases REM Sleep remains the same Wakefulness decreases	Impaired performance after doses

Table 5.1: Effects of different drugs on sleep performance

As can be seen many prescribed drugs affect the sleeping patterns of humans. The main effect was an increase in the SWS, which means that high arousal thresholds are needed to awaken from these longer deep sleep periods. The more alcohol or drugs people use will cause longer stages of deep sleep which may leave the person in a comatose state.

5.3 Communication Systems for Disabled Users

(Collins et al, 1981) Communication systems provides emergency and directional information. The requirements for disabled users during an emergency was by use of visual, auditory and/or tactile stimuli. The visual alarms were varied form rotating lights to flashing lights, also including letter sizes, background colours and text instructions. The tactile alarm used tactile communication where various surfaces had different textures to imply emergency escape or danger (warnings).

The auditory alarms in some cases may have to be supplemented by visual alarms and /or speech communication systems. The alarm must exceed the background noise by at least 15 dBA or exceed a maximum sound level with duration of 10 sec by 5 dBA, whichever is louder. The sound level should not exceed 120 dBA and the optimum frequency range for an audible fire alarm is between 750 - 1500 Hz because the lower frequencies had a better arousal rate than the higher frequencies.

Audible emergency signals must have an intensity and frequency that can attract attention of individuals who have partial hearing loss. People over 60 years of age generally have difficulty perceiving frequencies higher than 10 000 Hz.

Loss of high frequency hearing with age (presbycusis) is not limited to frequencies above 10 000 Hz. In fact, perception of frequencies as low as 250 Hz has been shown to be affected. Usually losses between 250 and 1500 Hz are less severe, with progressively more severe losses in the region from 2000 and 8000 Hz. This frequency dependent variation becomes more extreme with increasing age. However for all age groups, the region between 250 and 1500 Hz would be a region of minimal loss.

Those individuals wearing hearing aids will have a specific frequency region over which their aids provide maximum gain. Most types of hearing aid shows that maximum gain typically is present in the vicinity of 1000 Hz, the region most important for speech intelligibility.

The attenuation of alarm signal levels will be affected by the transmission of its signal in the building. Typical building partitions including brickwork, gypsum board on wooden studs, concrete and so on, have transmission loss values that increase rapidly with frequency.

Therefore in an effort to maximise transmission through these obstacles, the British Standard 5839 recommends maximum acoustic output between 500 and 1000 Hz. Unfortunately many warning devices have maximum output well above this frequency region. It appears that the frequency region between 750 and 1500 Hz is best suited as the region of maximum output for audible alarms.

5.4 Sleep Deprivation

Response to alarms is affected by sleep deprivation where an experiment by a researcher named Borbely, showed that subjects were tested three times a day ie. morning, afternoon and evening.

The following graph shows the performance to signal detection versus the amount of hours a person has slept ie. 0, 1, 2, 3, 5 and 7.5 hours. It shows a rapid decrease between the sleep deprivation of 3 - 7.5 hours, and a decrease in the rate of signals detected from the times of 0 - 3 hours. The graph clearly shows that sleep deprivation severely affects the signals detected. If the sleep deprivation increases for the next few days signals detected will also decrease.

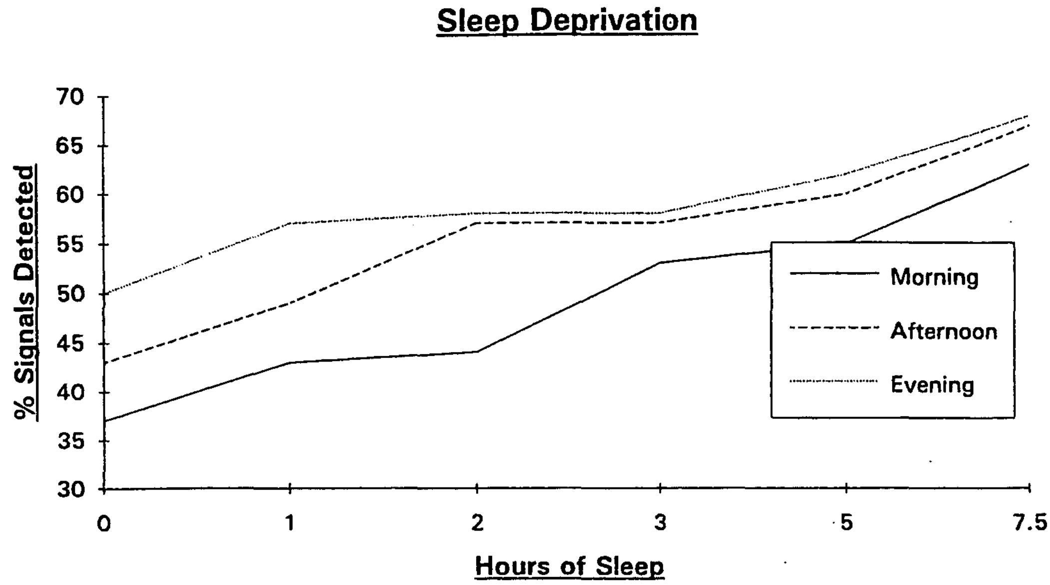


Fig 5.2: Sleep deprivation responsiveness to alarms

After sleep deprivation, the subjects would go to sleep almost immediately, and reached stage 4 within a few minutes, (Bonnet et al, 1987). Sleep loss caused increases in stages 3 and 4, and no significant changes in stage 1 and in the time taken to go to sleep.

The next graph shows that the some sleep stage amounts change for natural long, normal and short sleepers, (Horne, 1988). The participants of this experiment showed their normal amounts of sleep stages through the night (Baseline). Then they had 36 hours of sleep deprivation before sleeping again (Recovery). During recovery their sleep stage amounts had changed, where all participants showed large increases in SWS (40 %) ie stages 3 and 4 and smaller increases in REM sleep (20 %). Sleep length was only significantly longer in the normal and short sleepers.

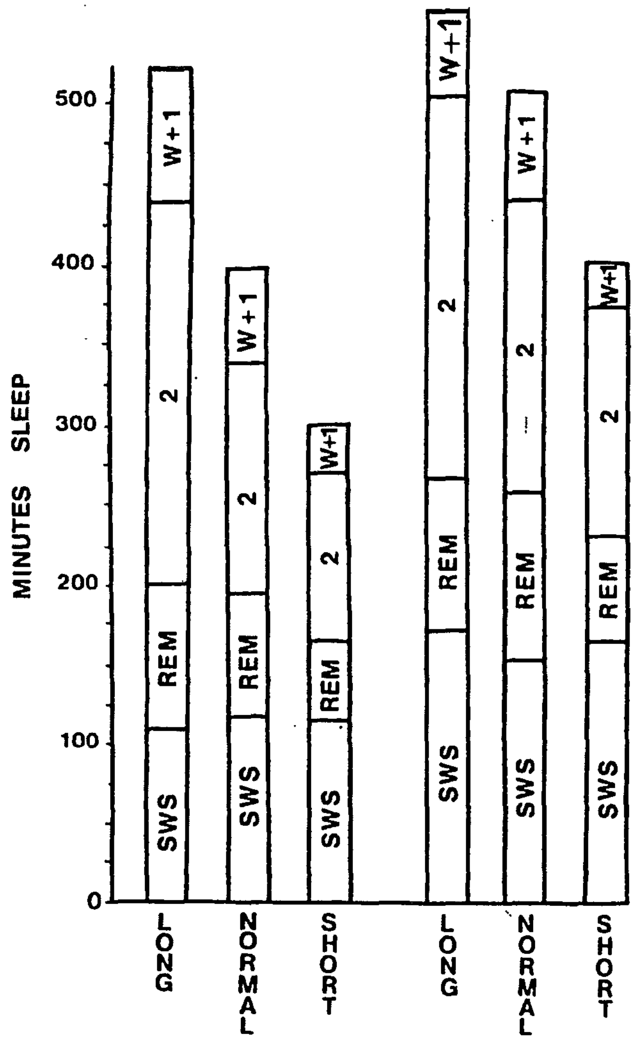


Fig 5.3: Sleep stage amounts for sleep deprivation

(Bonnet et al, 1987) In another experiment three groups of people were used, normal young adults (YN) 18 - 28 yrs, normal older males (ON) 55 - 70 yrs and insomnia older males (OI) 55 - 70 yrs. Their performance was studied under three conditions, baseline nights (BL), sleep deprivation (SD) for 64 hours and recovery nights (R). Performance was assessed by word memory tests and reaction times.

Results showed that YN had slower reaction times for nearly all awakenings than did ON and OI. All subjects responded slowly during SD but YN responded the slowest. The first R showed slow responses for all subjects but by the second R all subjects were responding the same as BL.

Word memory - YN recalled more words than others, where ON and OI recorded constant scores from BL to R. The YN decreased in memory and then regained position after second R.

Sleep EEG - sleep increased from BL to the first R. YN increased sleep in stage 4 and arousal thresholds were higher for YN (60 dBA) than older groups (45 dBA). ON and OI showed reaction times were less affected by sleep loss, initial recovery sleep and returned to BL faster than YN. Therefore YN were more impacted by total sleep loss.

5.5 Alarm Incorporation Into Dreams

People often report sleeping through an alarm because its significance was often distorted by the dream, (Bradley and Meddis, 1974). It was confirmed that external stimuli could be incorporated into dreams and be interpreted as part of a dream.

The arousal thresholds in the experiment showed that 43 % of the 39 retained dream reports showed incorporation of the stimulus when awoken from REM sleep. The reports were accompanied by an average arousal threshold of 70 dB, which was 10 dB above the threshold for non - incorporation reports, thus incorporation resulted in higher arousal thresholds.

Incorporation of olfactory stimuli can also interpreted as part of a dream, (Trotter et al, 1988). Out of 84 trials, 79 trials showed that people did not wake up to the stimulus where 19 % of the 79 incorporated the stimulus into their dreams. The participants could describe whether the stimuli were pleasant or unpleasant smells.

Experiments demonstrated that external stimuli presented during stage REM could be perceived by the subjects without apparent awakening, (Arkin and Antrobus, 1991). The experiments involved participants describing their dreams upon awakening from external stimuli. The stimuli consisted of either a 1000 Hz tone, a series of light flashes or a spray of water on the skin.

Upon awakening from the 1000 Hz tone subjects described it as a brief roaring sound, or an earthquake or plane crash. The light flashes were described as shooting stars or flash of lightning. The water spray was described as rainfall or a leaking roof.

There are a wide range of variability in the experimental results of incorporation of external stimuli and non - incorporation of external stimuli. Some of the causes are individual differences such as cognitive style, responsiveness and personality characteristics. Also type and intensity of stimulus such as water spray and strong anxiety levels cause an increase of incorporation into dream content.

Although REM thresholds are lower than stage 3 and 4, some REM thresholds values exceeded the loudest intensities needed to produce awakenings from the deep sleep stages. The reason was found to be an association with high intensity REM threshold values and reports of dreams, which was caused by incorporation of alarm into the dream. The participant found it difficult to awaken to an alarm because he thought he was dreaming.

The following are examples of actual dream reports during the activation of an audible alarm, (Rechtschaffen, 1966).

'I was in my room with a friend. We were arguing over the pronunciation of a German word. Suddenly my friend said that he had hidden a voltmeter in the closet which was going all the time. I said I had one too, and we both compared voltmeters. My friend's was unusual in that it lit up and made a noise every time he plugged it into a higher voltage. As he plugged it into higher and higher voltages, the sound got louder and louder.'

'I was at a lecture or something or other. Then I found myself in a laboratory giving sound tests to mice in a cage. I don't know what the mice were supposed to do or how they would react. As I gave louder sounds they just seemed to ignore it.'

5.6 Effects of the Building Layout

Factors affected by attenuation of fire alarm signal from source to receiver, (Robinson, 1988). The factors include absorption, sound reflection, reverberation and diffraction.

Most absorptions of sounds are by the furnishings, such as soft furniture, curtains and carpets. Acoustics ceilings can absorb from 50 % to 80 % of the sound energy that strikes the surfaces. Where a soft thick carpet with felt padding placed on the floor will absorb 50 % to 60 % of sound energy striking it.

It was shown that drapery and carpeting absorb high frequency sounds much more effectively than low frequency sounds. The high frequency sounds tend to have much more directivity, whereas low frequency sounds tend to spread out more uniformly in all directions due to their longer wavelengths.

The total sound pressure , in a space where the alarm is located, is the combination of pressure due to the original direct wave and the pressures due to the reflected waves. The direct sound dominates close to the alarm whilst the reflective sound dominates further out from the source ie in the reverberant field.

Another important concept is the sound caused by diffraction which occurs when the sound waves strike the edge of a solid barrier causing the sound waves to bend. Sound will also be diffracted as it passes through small openings such as the clearance at the bottom of a door. Diffraction and reflection enhance the transmission of the fire alarm signal.

An example of the sound level along a corridor, can be shown by dividing it into three sections. The first section is close to the sound source, which is the direct field in which the sound level decreases rapidly. Beyond the direct field is the second section where attenuation of the sound is dependent on the boundary materials and dimensions. The third section depends on the end wall, where most of the sound energy travelling towards the wall is reflected back. This causes an increase in the sound level near the wall and also decreases the rate of attenuation.

Under the worst conditions a fire alarm signal attenuates less than 6 dB in air for each doubling of distance from the source, but this is less in a reverberant field. Attenuation increases as the sound encounters a barrier, for example a 20 dB loss for a 1.75 inch solid oak door and a 45 dB loss for a 4 inch brick wall. But a small one square inch opening will greatly reduce transmission losses. Therefore the transmission loss from the sound source to the destination is greatly dependent on the acoustical attenuation properties along the path.

5.7 Identification of Fire Cues

Fire cues such as various smoke alarm intensities, smoke odour and heat were used to try and awaken subjects, (Kahn, 1984). The subjects were tested for their recognition of the fire cues and also for their response time to the fire cues. The smoke detector alarm intensities were 44, 54 and 78 dBA including a 44 dBA background noise.

It was found that the 78 dBA alarm had the highest frequency of detection and fastest response time by the subjects. Whereas the heat, smoke and 44 dBA alarm signal had the lowest frequency of detection and the slowest response times by the subjects.

Most subjects upon hearing the smoke detector alarm did not recognise it as a fire alarm signal and repeatedly slept through alarm warnings equal to those presented in a home setting. Kahn emphasises the high unresponsiveness to 4 of the 5 fire cues.

The following graph shows most responses to the fire cues occurred in the 20 th minute, which was much too long. Whereas the next highest number of observations occurred in the first minute. The graphs following will show that the slow response times were for the low detection fire cues eg. smoke and heat cues.

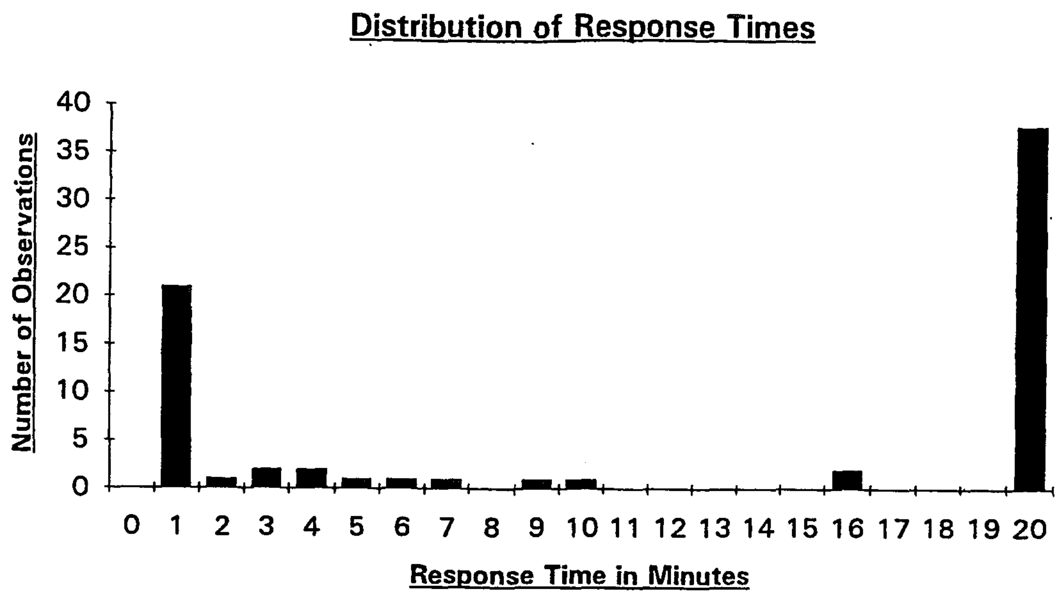


Fig 5.4 Distribution of response times

The next graph shows the frequency of detection of fire cues with most detection for the 78 dBA alarm, significantly higher than the 58 dBA alarm. The other fire cues had a very low frequency of detection.

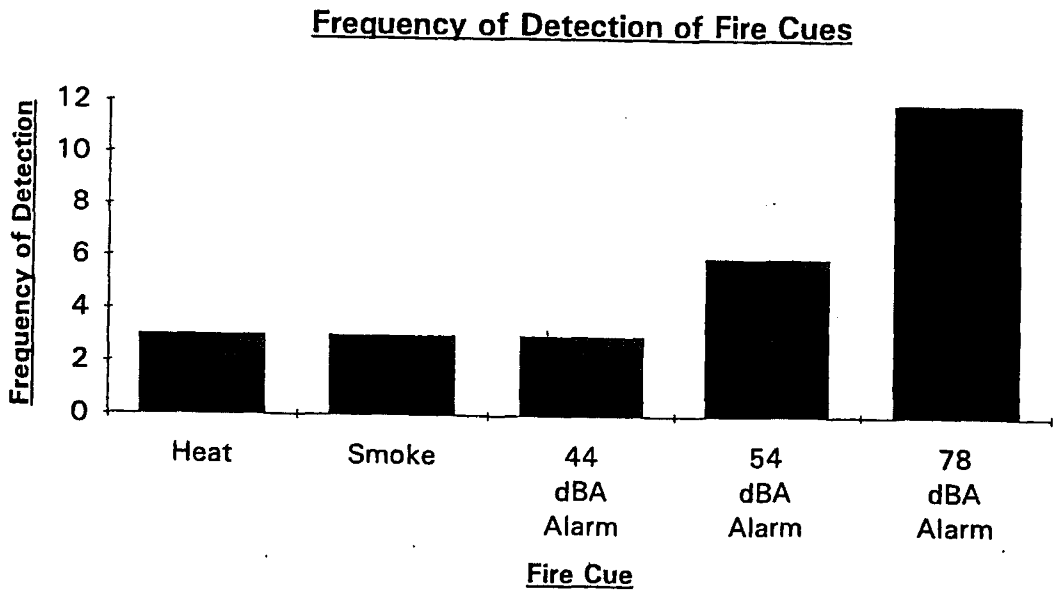


Fig 5.5: Frequency of detection of fire cues

The last graph shows mainly that the fastest response time was significantly highest for the 78 dBA alarm of 50 sec. Whereas the heat, smoke and 44 dBA alarm had the slowest response times ranging from 800 sec to 1000 sec.

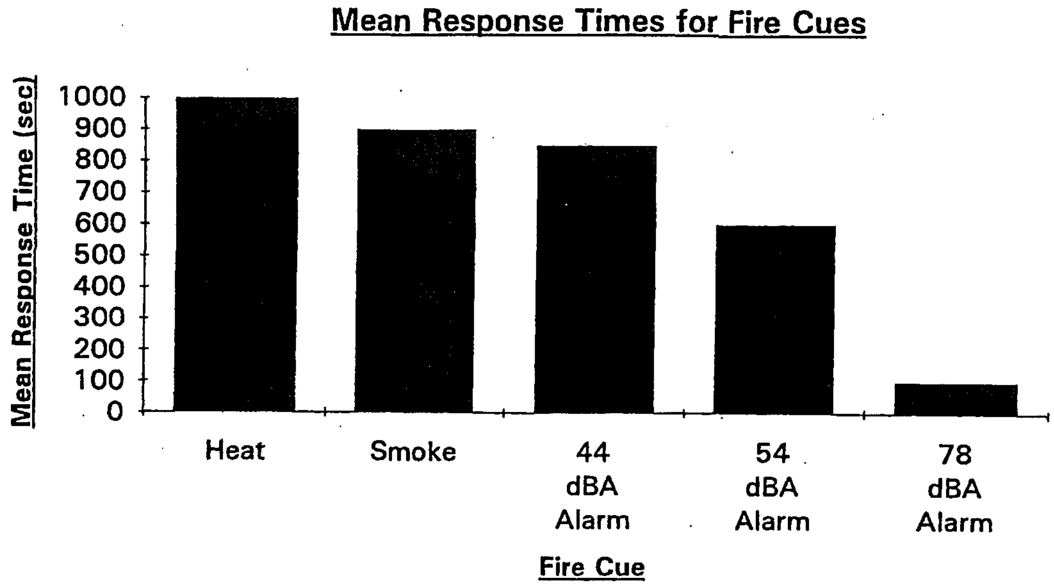


Fig 5.6: Mean response times for fire cues

CHAPTER 6. HUMAN BEHAVIOUR IN FIRES

6.1 General

In this chapter highlights of the importance of human behaviour in fires are shown, including how panic is not always the reason why people die in fires. It will be shown that humans follow a pattern in a fire from all the confusion and one can take advantage of this to train people to use a systematic response to a fire. Some questions were to find out, what the reasoning and motivation was behind a persons action in a fire emergency. Why would a person take a particular course of action, is it panic, past experience, heroism or stupidity?

6.2 Human Behaviour

The whole behavioural process is taking place as the fire itself may be rapidly developing and what is an appropriate action at one stage may be quite inappropriate a minute later, (Paulsen, 1984).

Human behaviour in an emergency can only be properly judged against the individuals awareness of the options available at different stages throughout the fire. For example, familiarity with the building, general constraints of the fire situation and levels of expertise.

Panic may be characterised by an irrational or maladaptive behaviour where the outcome may be fatal, for example, jumping from a high rise building or returning into a building. But it is more important to consider the circumstances which caused the behaviour, not the inappropriateness of behaviour as judged from another persons perspective.

In a fire situation people may have been forced into a position where they have been unable to act immediately because the options available have been reduced. The resulting action may be at the time the most sensible and logical action to take. For example the fire in the Empire hotel, New Zealand where a person jumped to his death from the third floor may have been seen as panic. But this person was forced into a corner from the heat of the fire with only a window as the logical means of escape.

Maladaptive behaviour is when a group of people are trying to escape out of a building in an emergency, where at the same time another person may be trying to get into the building disrupting the occupants escaping. But to this person it is regarded as adaptive behaviour because the person may be trying to find his / her child.

Therefore the concept of panic which is most commonly associated with fire emergencies is regarded by many researchers as a myth. Although evidence of panic reactions should be looked at, it has been believed that more attention should be focused at other failures such as response to alarms and re entry of a burning building.

6.3 Domestic Fires in the Home

(Canter, 1990) Given the high proportion of deaths which occur in domestic fires people frequently rely on others for information and check the information they are given. It is also apparent that people frequently have to cope with smoke and other environmental difficulties in fire events. Furthermore, even though they often come into contact with smoke and other fire cues there is a tendency to ignore or misinterpret this as being an indicator of a serious event.

The sequence of events for domestic fires are as follows:

1) In the very early stages people report noticing cues but finding them ambiguous, often hearing noises, misinterpreting or ignoring these, or discussing them with anyone present. If the cues persist, investigation will take place to find the source of the noise or smell. The only variation from this initial group of actions is if smoke or the fire is encountered directly.

2) If investigations follow the early ambiguous cues, then it inevitably leads to encountering smoke, either within the room of fire origin or outside this room if the smoke is spreading. If the latter, people are still likely to enter the room where the fire is.

3) A direct encounter with the smoke or fire generates variability in the likely response sequence. This variability is a function of the stage of fire growth and location of the fire at the time when it is encountered. Much of the variability present can be accounted for by differences between men and women, occupants and neighbours. In other words, it is the difference in the roles which people have in the setting which underlies their different behaviour.

4) The main differences exist at the initial interpretation stage and the behaviour following investigation and encountering the smoke. While both males and females tend to misinterpret ambiguous cues, males are more likely to do so and delay investigation. The response of a female may be delayed by interaction with a male if present. Eventually one of them initiates investigative activity. Both males and females are likely to investigate.

5) If informed by someone who has returned to say there is a fire, the tendency is to check this information for oneself. The indications are that this may be more likely if males initially receive a warning from females than vice versa. This tendency to continue investigation after being informed, is particularly characteristic of domestic as opposed to other building / occupancy types. It is apparently related to the role of the individual in his or her own home as well as the proximity of a fire. More responsibility may be felt for the safety of others who are likely to be present and for the prevention of damage.

6) The variability of the actions which follow the encounter with the smoke and fire itself is explained by male / female differences. Females are more likely to warn others and wait for further instruction (for example if husband and wife are both present). Alternatively, they will close the door to the room of fire origin and leave the house.

7) In both cases females are more likely to seek assistance from neighbours. Male occupants are more likely to attempt to fight the fire. Males are also more likely to search for people in smoke and attempt a rescue.

6.4 General Models

The fire is seen as having three broad stages:

1) the individual receives initial cues and investigates or misinterprets these initial cues,

2) once the fire is apparent the individual will try to obtain further information, contacts others or leaves,

3) thereafter the individual will deal with the fire, interact with others or escape.

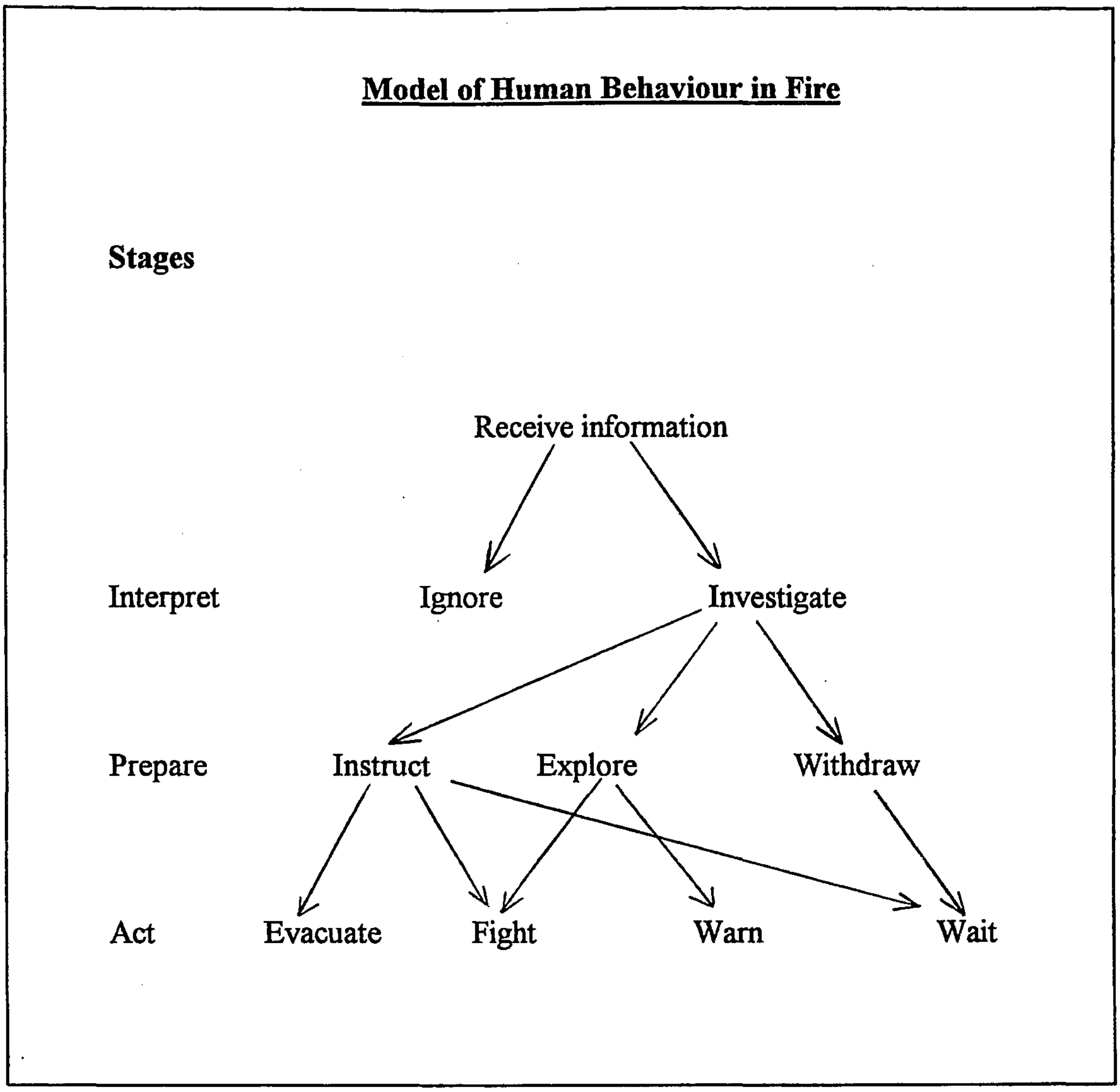


Fig 6.1: Simplistic model of human behaviour in a fire

Definitions of the above terms:

Interpretation

Individuals may or may not have realised there is a fire. An understanding of their behaviour must take account of whether or not they have defined their situation correctly. Because people act on their definition of a situation the clues and information that lead to this must be taken into account, with due consideration of the influence of both the place and roles of the people concerned.

In a domestic fire the presence of smoke is a clear indicator of the need for fire related activity which is more likely to follow as their is no reliance on others for action. In an organisation a fire will be quickly interpreted if a strict hierarchy is already in existence, with a senior member clearly responsible for defining the actions of his / her juniors.

Prepare

Once the fire has been defined the 'prepare' stage occurs which includes instruct, explore and withdraw. The particular type of occupancy is likely to have a great influence on exactly how this stage develops.

1) Instruct. Who does the instructing depends almost entirely on their existing role in an organisation.

2) Explore. Consists of a variety of activities associated with establishing exactly what is happening. It frequently consists of going to the room of fire origin and trying to see the fire directly, being a development of other less intrusive investigations.

3) Withdraw. The phenomenon of withdraw / wait is most typical in the context of hotels where the privacy and self - reliance associated with being a hotel guest seems crucial.

Act

The final stage depends considerably on role, occupancy and earlier behaviour and experience. With early definition it may be possible for early evacuation or effective fire fighting to occur. Both males and females will fight the fire but a more dynamic role is apparent for males.

Wait may be confined to hotels and guests, however in other circumstances people may wait after giving instructions.

6.5 Actions Taken

Decision making is a very important process especially during the process of various actions taken in a fire emergency. This is because every fire situation is different and coping with an emergency may require one to adapt to the situation rather than follow a set of previously memorised actions.

The more frequently people had received training on what to do in a fire, the more likely they were to raise the alarm and /or organise evacuation from the building as a first action, regardless of familiarity with the building.

Whereas people who were not as familiar with emergencies were more likely to go back into the building or delay evacuation while trying to get their personal effects, this may be due to security reasons or to give them some comfort in an unfamiliar environment.

Behaviour category	Percentage of a persons first action
1. Take some fire fighting action	15
2. Contact fire brigade	13
3. Investigate fire	12
4. Warn others	11
5. Do something to minimise danger	10
6. Evacuate oneself from building	9.5
7. Evacuate others from building	7

Table 6.1: The following table shows the first actions taken by people in a fire. The categories describe 80 % of the first actions taken.

Information received from the fire service was used to assist in study of occurrences of fire. Interviews where conducted where the participants in a real fire were told to give a detailed account of everything that happened over the course of the fire. Analysis required the breakdown of the participants actions into single acts, where notes were taken of the position in the sequence of events and physical location of each act. For each building occupancy type it was possible to ascertain which act had followed each of the other acts. The acts where taken from the agenda for interview namely:

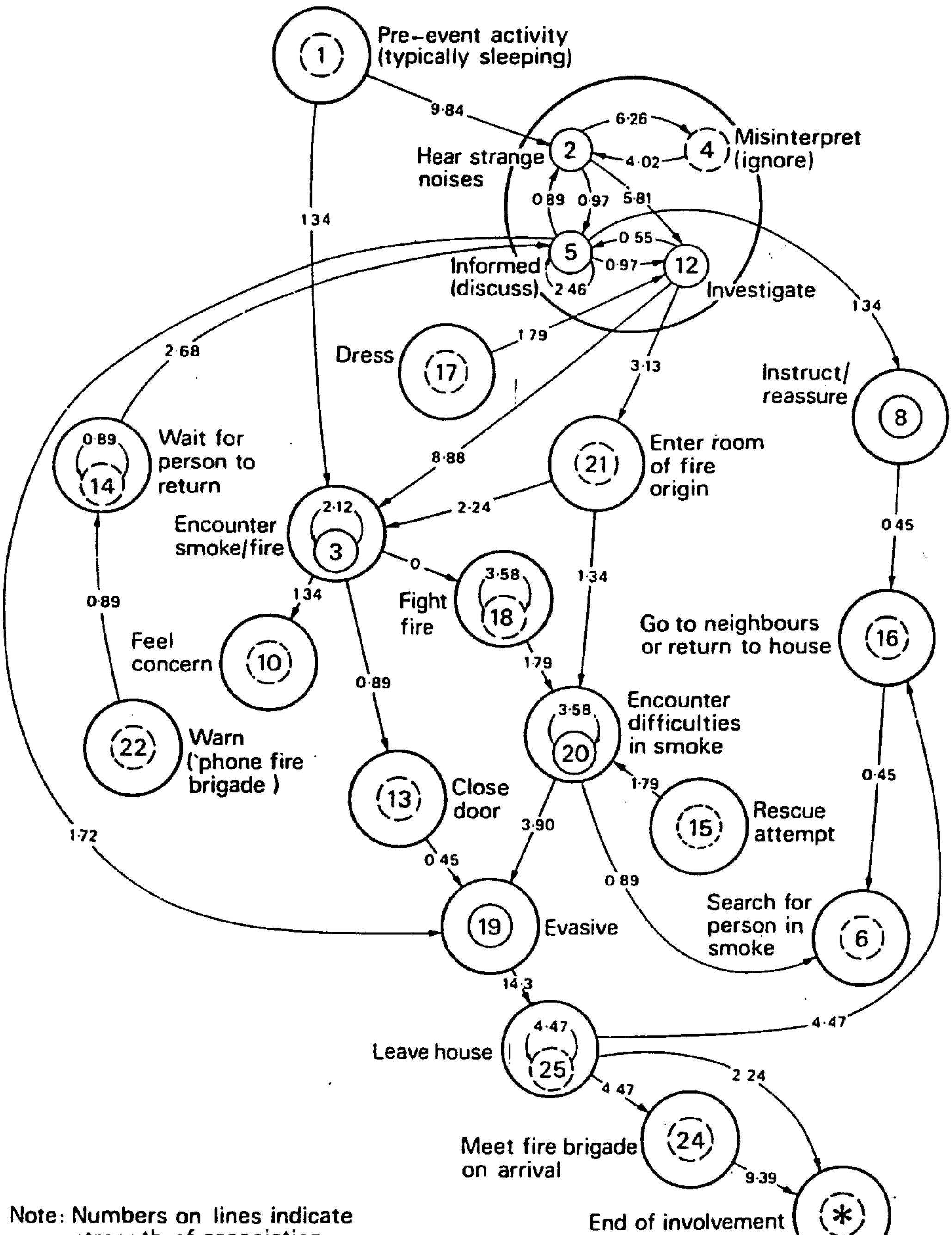
- Recognition of fire
- Location of occupant
- Ongoing behaviour
- Sequence of actions
- Perception of the situation including:
- Other peoples behaviour
- Physical circumstances of fire
- Time estimates
- Related past experience
- Background details, such as:

- Role of person
- Layout of building
- Fire damage.

The acts were collected together and then their sequences were determined where it was shown that the greater the intricacy of the behaviour, the greater the number of acts and the more complicated the connections between each act.

The resultant set of related act sequences were represented in the following decomposition diagram. The decomposition diagram shows that the acts are represented by circles whereas dashed circles indicate acts which occur with a lower frequency and also give an idea of behavioural relationships. The arrows represent the relationships between the acts. The numbers next to an arrow represent the strength of association between the two acts.

The diagrams are valuable in that it summarises in a visual form the complexity of events taking place.



Note: Numbers on lines indicate strength of association between two acts linked by arrow

Fig 6.2 Decomposition Diagram

6.6 Effects of Alarms

(Canter, 1990) The study evaluated the effectiveness of conventional alarm systems in motivating egress found them to be ineffective and associated with the following three failures:

1) A failure of people to differentiate fire alarms from other types of alarms

People rely on being familiar in which they perceive the alarm but if not familiar they need additional confirmation that the alarm is a real fire alarm.

2) A failure of people to regard fire alarms as authentic warnings of a genuine fire. Most fire alarms are usually heard as drills and false alarms where it may send them into a sense of false security.

3) A failure of alarms to present information which will assist fire victims in their attempt to cope with the fire.

People who recognise a fire alarm will initially attempt to authenticate the alarm warning and then establish a course of action they think appropriate. The frequency of false alarms, meaning of the alarm and people looking for evidence of a fire instead of evacuating are all factors which will determine the effectiveness of alarms in producing immediate evacuation.

It was found that motivation to evacuate is related to the following:

Gender. Women are more likely to evacuate immediately than men, who initially intend to fight the fire

Knowledge of an escape route. If people are aware that an escape route exists, then they are less likely to leave because they feel less threatened by the fire. Thus the motivation to escape is only dominant when other objectives, such as extinguishing the fire are perceived as unobtainable.

Intensity and spread of smoke. The presence and density of smoke is directly related to the level of perceived threat, so that smoke encourages people to leave. The perceptional relationship cited is believed to outweigh the physiological and spatial disorientational difficulties.

Previous experience of fire. People are less likely to leave if they have experienced a fire previously. It would appear that people who have learnt that they can cope with a fire threat believe that they can pursue objectives other than evacuation.

Training. The more training an individual has received, the more the person is likely to attempt to control the threat and less likely to leave. Again the learning factor is important but it is likely that fire training in occupancies such as hospitals will give individuals a set of organisational responsibilities to which they are responding, independently of the intensity of the threat.

Direct threat perception. If a fire is judged to be extremely serious, then those facing the threat are more likely to leave. In the early stages of fire growth people have misunderstood the early cues, nature and speed of the fire growth. Some of these errors have led to many fatalities where people were unaware of the danger and thought they could handle the situation.

A common belief was that dangerous fires are experienced as conflagrations but its presence can be indicated by early cues such as sounds like glass breaking, people shouting and smells of smoke.

Other beliefs were that people thought that the growth of a fire was slow and manageable, but the rate of fire increases exponentially with time in only a matter of minutes, before it cannot be contained.

An experiment by Canter was used to study the subjective estimation of fire growth. Twenty individuals were shown seven photographs of an actual fire growth taken from the reconstruction or the Stardust Club tragedy, Dublin, 1981. Each person was asked to estimate the difference in time between each stage of fire growth shown by the photographs.

The results as can be seen from the graphs are that the people under estimated the rate of fire growth. It also shows that people can predict the initial fire growth but are unable to predict the times due to changes involving lateral spread of flames and obscurity due to smoke production.

Hopefully the graph will show that upon hearing a fire alarm, evacuate immediately and don't re - enter the building.

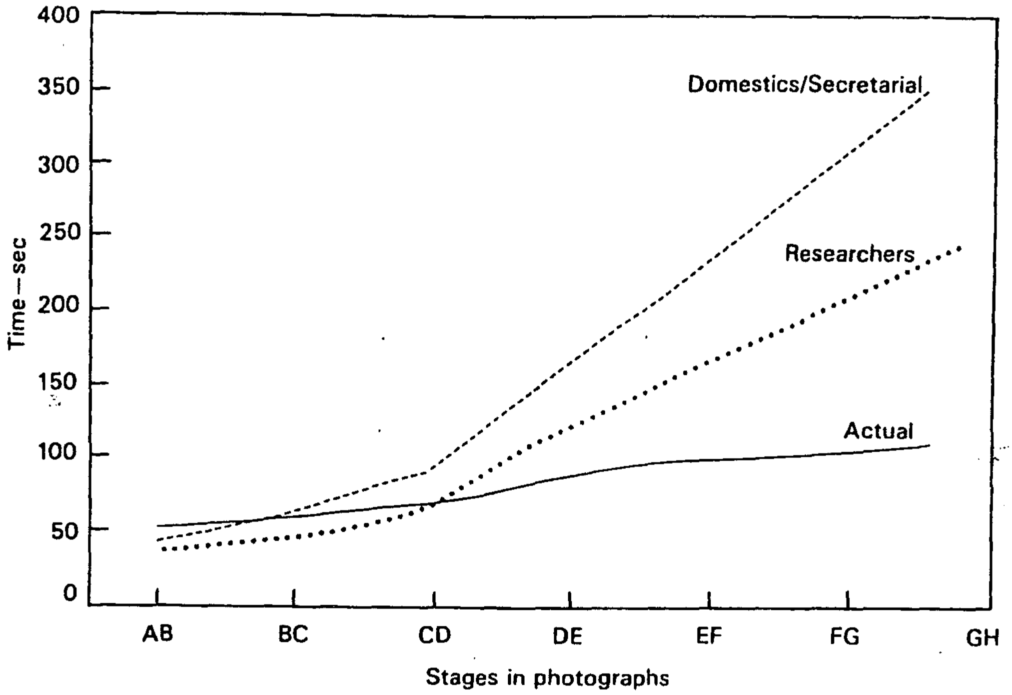


Fig 6.3: Perceived vs actual times between fire stages

(Kahn, 1983) He shows a model based on Schwalms which shows the behavioural times necessary to complete human fire behaviours.

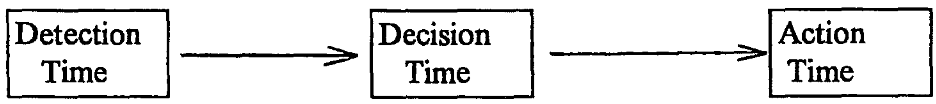


Fig 6.4: Simple model of response times

The delay in response to fires can be fatal and the importance of early fire detection cannot be stressed. He states that any time lost between fire onset and fire detection may be critical, due to the fact that egress routes may become impassable by the time the fire detection occurs.

(Demers, 1978) In his article of ten students die in a college dormitory fire on the fourth floor due to highly combustible Christmas decorations piled up in the corridor. The high fuel content in the decorations caused a very fast fire to develop.

The building had a fire alarm system that consisted of manual pull stations, three combination rate - of - rise, fixed - temperature (135^{0}F) heat detectors and interior alarm horns but, no smoke detectors or automatic sprinklers. The fire detection was manually activated by the fire alarm pull station located on the fourth floor, this action was too late as fire had already began developing and it did not give enough decision and action time for the occupants to escape.

A fire at St Joseph's hospital had been detected by a staff member, at the time of the fire it had an occupancy of 171 patients including community citizens. The patients were evacuated within seven minutes from the area of fire origin. It took 19 minutes to evacuate the entire hospital which was deemed a success. The investigation had shown that the period between detection of the fire and the arrival of the fire department was the most crucial life saving period. Because within three minutes the staff had evacuated 22 patients from the area of fire origin just as the fire service arrived.

The evacuation was successful because of the benefits of a comprehensive staff training program provided by the fire department hospital team and in - house drills. (Lerup, 1978) For fires in nursing facilities there are general principals of emergency behaviour which are a set of life saving actions made up of behavioural episodes. The life saving actions are described as *episodes* which may occur for a variety of purposes, *objectives* such as arousing a patient and *mechanism* such as pulling the alarm or shouting at others.

The table shows the episode, objective and mechanism array.

EPISODE	OBJECTIVE	MECHANISM
Investigate		
Alarm	Notify fire department	Pull fire alarm
		Phone fire department
		Seek help
	Alert staff	Pull fire alarm
		Shout
		Face to face
	Arouse occupants	Pull fire alarm
		Shout
		Face to face
Attack	Manage smoke	Ventilate
		Compartmentalise
	Control fire growth	Compartmentalise
		Manual suppression
		Isolate fuels
Flight	Move to holding area	Vertical movement
		Horizontal movement
	Move to outside	Vertical movement
		Horizontal movement
Rescue	Remove occupants	Carry
		Lead
	Manage evacuation	Hold in place
		Direct movement
No Action		

Table 6.2: Life saving actions

These sequences of life saving actions were derived from ten fire scenarios by Nelson, Lerup and Canter. It was shown that the nursing staff involved themselves in decisive action such as raising the alarm, investigation and rescue. Whereas the patients confirmed their indecisiveness by showing a wide range of actions including a high percentage of no action compared with the nursing staff.

CHAPTER 7. STATISTICS

7.1 General

The following statistics are taken from New Zealand, Australia and USA. Comparisons were made from the fire statistics by finding when and where fires were occurring. It was shown from the statistics what type of people were dying ie. age and sex, and also what the victims actions were immediately before death occurred in the fire. Finally the smoke detector statistics in the USA were investigated to find out the causes why people were still dying with these detectors.

7.2 Australia, New Zealand and USA

Australia

23 % of all fires were structural fires, where fires in residential properties accounted for 58 % of all the structural fires. 77 % of all residential fires occurred in one and two family dwellings.

Fatalities occurred mainly in structural fires where 60 out of 107 fatalities and 624 out of 879 casualties were reported. 32 fatalities and 335 casualties occurred in one and two family dwellings. Most of the casualties occur from 1 pm to about 11 pm, where most fatalities were occurring between 1 am and 2 am.

United States of America

22 % (1 965 500) of all fires occurred in residential properties. 79 % (3622) of all fire deaths occurred in the home while 74 % (19125) of all injuries occurred in residential properties.

The peak period for home fires was between 6 pm to 7 pm which reflects the effects of household members arriving home. The peak period for home fire deaths, however, was early morning, 2 am to 3 am when most people are asleep. The fire deaths increase from 9.8 % at 10 pm to 14.9 % at 4 am then decrease to 8.1 % at 8 am. As of interest, a residential fire occurs every 74 seconds.

New Zealand

40 % (8548) of all fires occurred in structural property. Where residential fires accounted for 8138 fires and one and two family dwellings accounted for 7545 of the residential fires.

67 % of all fatalities occurred in residential areas. Most fires occurred between 5 pm and 7 pm with a small amount of fires occurring between 12 pm to 8 am (200 to 800 fire incidents) when most people were sleeping.

7.3 Fire Fatalities

As most fires occur in the residential areas I will now look at times when these fires were occurring.

The following graph shows that the peak periods for home fires occurred between 4 pm and 8 pm for New Zealand, (Irwin KDJ, 1997). This is due to the fact that the leading causes of most home fires were by cooking of evening meals and / or turning on the heaters during the Winter seasons.

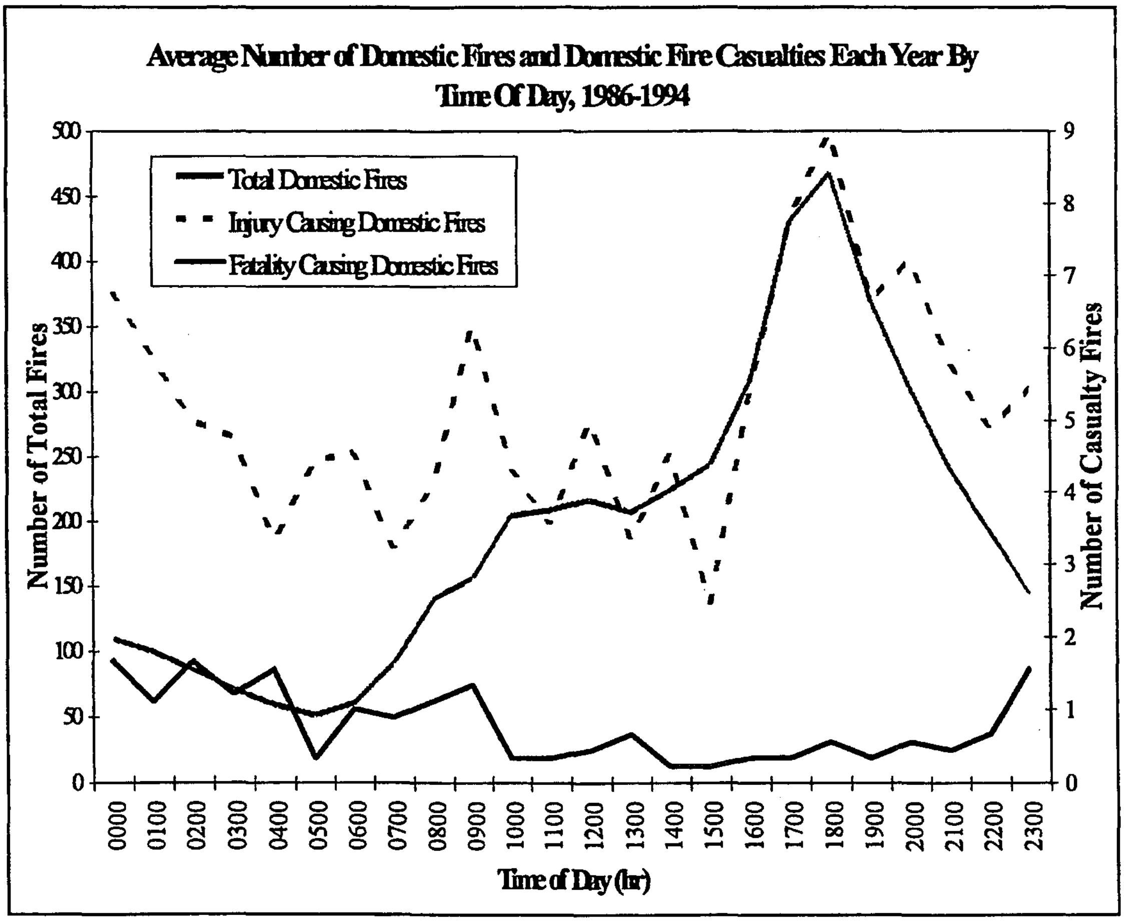


Fig 7.1: Number of fires and causalities in New Zealand, 1986 - 1994

Most fire fatalities occur very early in the morning for all three countries when people are sleeping, even though the previous graph showed that a very small amount of fires were occurring early in the morning. There were very few deaths occurring throughout the day and most of the night

The following graph show that the peak period for fatalities of home fire deaths were occurring between 1 am and 4 am, when most occupants are sleeping, (Hall, 1996a). This is a graph taken from the USA statistics and is very similar to Australia and I will use it to represent New Zealand.

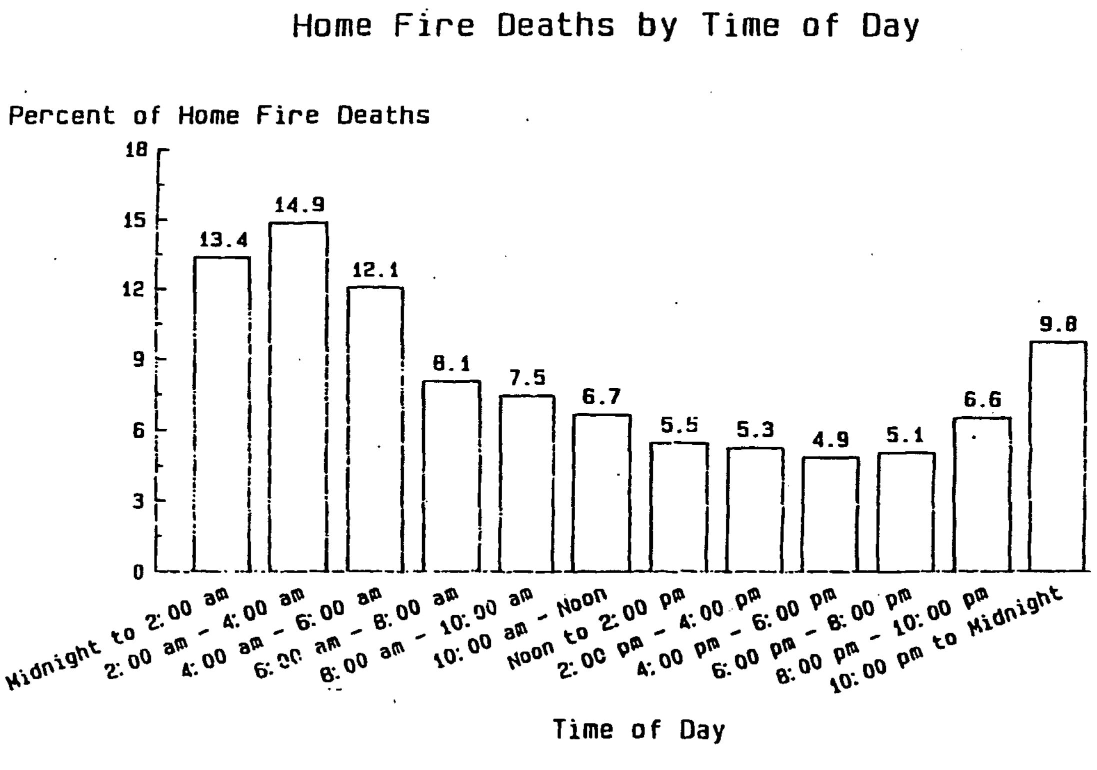


Fig 7.2: Fire deaths by time of day

Victims actions before or during a fire can mean the difference between life and death. The following graph shows the victims actions immediately before their fatality according to fire statistics in New Zealand and Australia. The most numbers of fatalities were occurring when people were sleeping followed by other actions such as a heart attack or stroke. The third most common cause was by people trying to escape ie. they reacted too late or left the fire establishment too late resulting in their deaths.

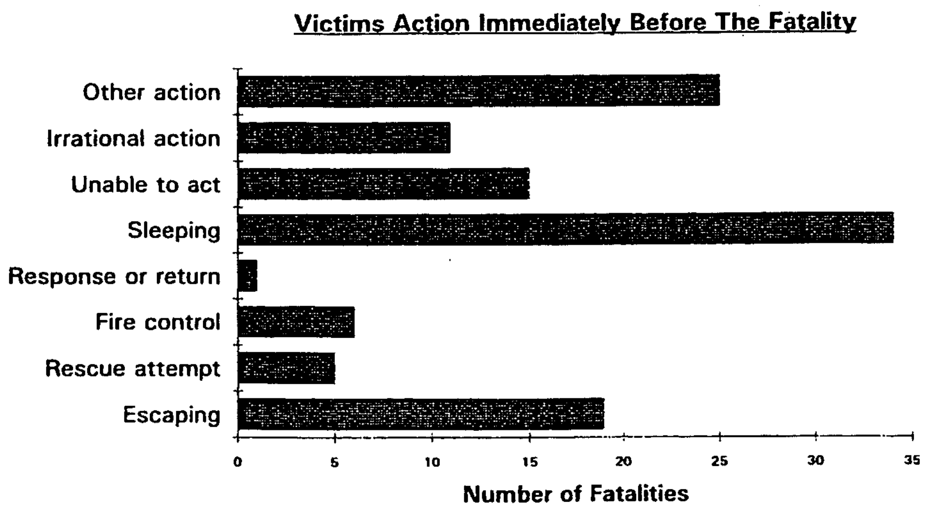


Fig 7.3: Victims action before fatality

The following graph shows ages of the victims killed in a fire from the Australian and New Zealand statistics. It can be seen that the highest fatalities were occurring in the range of 0 - 9, 20 - 29 and over 89 age groups. The age of victims with the lowest fatalities occurred between the 70 and 80 year old age groups.

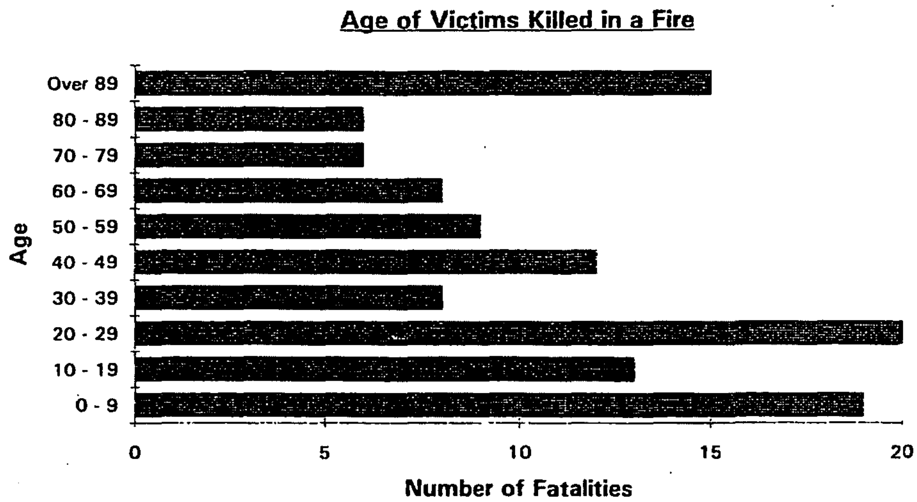


Fig 7.4: Age of fatalities

7.4 Household Smoke Detectors

(Hall, 1996b) For the USA it has been shown that up to the year 1995, 93 % of homes had at least one smoke detector, this approximates to 13 of every 14 households.

Approximately one fifth of all detectors were non operational, this is mainly due to dead or missing batteries which accounted for 69 % of all detectors that failed to activate in a fire. Other causes were incorrect installation (12 percent) and incorrect location (11 percent). Installation errors were due to poor location of detectors such as, to low on a wall, too close to an air return or located in a dead air space.

The leading cause for missing batteries was that they had been removed because of nuisance alarms. The reasons for this were that most alarms were installed too close to areas which have a potential source of smoke, steam or moisture eg the kitchen. Other solutions apart from the detector relocation would be to substitute the more sensitive ionisation - type detectors with the photoelectric - type detectors and more frequent, effective detector cleaning.

The reason for dead batteries is mainly due to poor maintenance ie not regularly checking and testing the detector periodically say every month.

One third of all homes fires were reported to have occurred in homes with smoke detectors. The reasons for the relatively low numbers of reported fires has been first that the kind of households that would be less likely to buy or own smoke detectors such as run down poverty stricken households. Secondly, smoke detectors discover some fires so early that they can be controlled by the occupants without involving or notifying the fire department.

The homes that do use a smoke detector typically have a death rate of about 40 - 50 % less than the rate for the homes without detectors. That means homes with smoke detectors have slightly more than half the risk that a death will occur in the event of a fire.

Table showing deaths per 100 fires in the USA.

Year	**Detectors Present**	**No Detector Present**	**Death Rate With Detectors Present**
1985	0.62	1.02	39 %
1986	0.55	1.07	49 %
1987	0.59	0.99	40 %
1988	0.66	1.16	43 %
1989	0.65	1.06	39 %
1990	0.61	1.14	46 %
1991	0.53	0.84	37 %
1992	0.57	1.03	45 %
1993	0.50	1.03	51 %
1994	0.51	1.03.	51 %
Average	**0.57**	**1.04**	**45 %**

Table 7.1: Death rate of homes with / without detectors

CHAPTER 8. RECOMMENDATIONS AND CONCLUSIONS.

8.1 Summary

The main points from this report was the high unresponsiveness of people to a fire alarm during sleep. Many people failed to awaken to the fire alarm because the sound was not loud enough or many other problems such as background noise was too high. The unresponsiveness was also due to unfamiliarity to the fire alarm due to so many fire alarm signals where if a person awoke to the fire alarm they may not recognise it as an emergency fire alarm and go back to sleep or delay there response to it. It was also shown that people who were motivated or trained were very successful in awakening to an alarm.

There is a trend between deep sleep and time of fire fatalities where both events occur at its highest in the first half of the night. There is enough evidence from various experiments to show that even with audible alarms people still will remain asleep during activation of an alarm especially during deep sleep.

8.2 General Conclusions

The factors affecting performance after sudden arousal were: stage of sleep, time of night and nature of required performance (human behaviour).

It was also shown that the young adults ie 20 - 29 and under 9 year olds were the most resistant to awakening to a fire alarm due to more SWS sleep. This is reflected in the statistics which show that most fatalities occur in these age groups.

Sound was found to attenuate greatly if it has to travel from one room to another. A solution would be to have the audible alarm device in the occupied space ie. bedroom.

The smoke detector alarm signals have acoustic spectral characteristics that vary among manufacturers models. Most units have bimodal energy peaks with the primary peak around 4000 Hz and the secondary peak around 2000 Hz.

Most sleep occurs in stage 2 for all ages where younger people spend more time in stage 4 sleep than the elderly. Elderly people awaken more rapidly from sleep, and their hearing impairment to higher frequency may need changes in the characteristics of the alarm.

Arousal thresholds as a function of sleep stage was related to sleep depth as a greater alarm intensity was required for a response from wakefulness to stage 4.

Arousal as a function of signal meaningfulness and sleeper motivation responded more frequently to motivating stimuli eg. hearing sounds such as own name or baby crying.

Use of drugs and alcohol causes longer deep sleep when one becomes more intoxicated, especially at the beginning of sleep, and arousal is at a slower rate. Also a smoke alarm may not wake a person who is intoxicated.

8.3 Recommendations

Use of a unique, universal emergency fire alarm signal with a sound that could easily be recognised as a fire alarm cue and to eliminate confusion from all other signals.

The 75 dBA sound level in detectors according to New Zealand Standards are adequate in awakening a person when this sound level is heard at the bed - head with all doors closed.

Compulsory smoke detectors in New Zealand including public education about installation of smoke detectors, and maintenance including planning and practising evacuation.

Audible warning systems should as part of their design and installation, include consideration of the following:

1) the design characteristics of the alarm (including power spectrum, frequency response and directivity),

2) the location and spacing of the alarm devices,

3) the sound transmission properties of the building in which the system is to be installed,

4) the background noise levels over which the signal must be heard.

8.3 Further Research

More research is needed into incorporation of alarms into dreams. A study of how the dream incorporation affects the awakening threshold and time to react to the alarm. See if there are any possibilities as to lowering the threshold and gain knowledge of how much of a problem this issue is, by interviewing survivors in a fire and by experimentation and research.

Further research into self training methods to improve human awakenings, such as motivational techniques, especially to recognise fire alarms in their household.

More research is needed for alarm characteristics and presentation of audible alarms to target awakenings from deep sleep (ie. bells, horns, frequency and meaningfulness of the alarm).

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