Can fatal fires be avoide ? The impact of domestic smoke alarms on human safety

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This paper presents a summary of the findings from projects at SINTEF NBL concerning the human safety aspect in fires, focusing on fire safety in domestic houses. How domestic smoke alarms affect the safety is chosen as a term of reference. Results from statistical surveys of fire deaths in Norway compared with other countries are used to describe who dies in fires. The use of and requirements for domestic smoke alarms in different parts of the world is briefly presented. The sensibility of ionic and optical smoke detectors in smouldering and flaming fires are analyzed, and an evaluation of the effectiveness of the two detector principles is made based on the test results and expected frequencies of these types of fires. Available time for evacuation is discussed based on expected time to untenable conditions, expected time to flashover, expected time to intervention from fire brigades, and the expected response time for smoke alarms. Different needs to evacuate different groups of occupants (children, elderly people, disabled) are also discussed. An analysis shows that the Norwegian requirement of domestic smoke alarms is highly cost effective. In Norway between 40 and 60 people die in fires every year, and it is estimated that 10 lives is saved every year because of installed domestic smoke alarms. There is, however, an improvement potential for the effectiveness of domestic smoke alarms. Detectors and alarms can be improved technically, requirements to power supply can be set, the installation can be optimized and the extent of use can be increased. All these improvements will increase the probability that an installed smoke alarm really is functioning in case of a fire, both concerning detection and alarm.

Key words: Fire safety, fatal fires, smoke alarms

1 Who dies in fires, why and where does it happen?

1.1 How many persons die in fires?

The number of fire fatalities in a country varies to some degree around an average value from year to year. The Geneva Association has been collecting and systematizing international fire statistics for more than twenty years [1], and the ranking between the countries have more or less been unchanged during the last 10 years, see Figure 1. It is also interesting to notice from the figure that most countries in this list have reported a decrease in number of fire deaths over the period 1992 to 2001. The numbers in the statistics are far from exact, but they are believed to be a fairly good basis for comparison of fire death conditions between different countries.

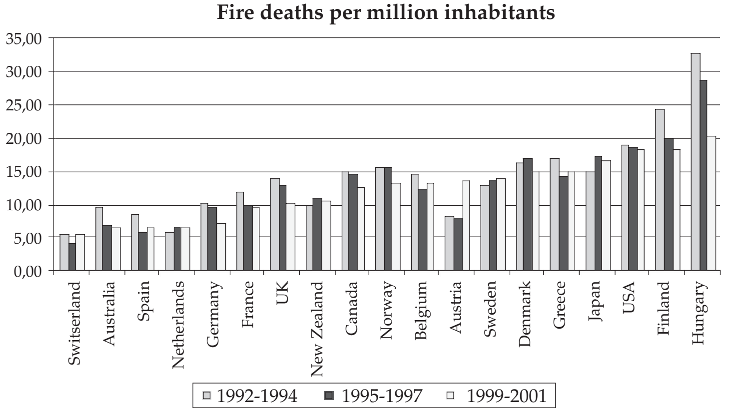

Figure 1. Number of fire fatalities per million persons in different countries in the periods (1992-1994), (1995-1997) and (1999-2001). The numbers for USA for the latter period include 2791 fatalities following from the World Trade Center disaster 11th September 2001 [1].

According to the material from The Geneva Association, Switzerland had the lowest rate of fire deaths per population in the period 1999-2001, with a value of 5, 6 fatalities per million inhabitants, closely followed by Australia, Spain and the Netherlands. Hungary was the country on the list with the highest value of fire fatalities, i.e. 20.6 per million people. Norway had the lowest number of deaths among the Nordic countries, with 13.4 per million inhabitants.

The fatalities reported in these statistics are not confined to deaths resulting from fires only in buildings, but include fatalities resulting from fires with a great variety of locations. It is, however, assumed here that a relative ranking between different countries will be roughly the same as shown in Figure 1 when considering solely fires in buildings.

1.2 *Who die in fires?*

Several studies in different countries have been undertaken where fire fatalities are analysed with respect to why, how and where fires start, and concerning how the victims in these fires can be described. In Norway, SINTEF NBL has performed two research projects on this field. One project analysed the fire fatalities in the period 1970-1979 [2], while the other project analysed Norwegian fire deaths in the period 1978-1992, and compared the results with the results from the first project [3]. Later on, an analysis of the impact of different actions against fire was performed, and the effect of smoke detectors on the number of fire fatalities was one of the research objectives. An analysis of factors describing fire victims was one of the methods [4, 5, 6].

About 2/3 of the fire victims are men. This is an international phenomenon. In the Norwegian studies, it was shown that the number of victims per fatal fire is decreasing, i.e. it is most likely that people die alone in a fire. There is a tendency that the proportion of women dying alone in a fire is increasing, and the age of female victims is increasing.

There are many elderly persons among the Norwegian fire victims. Most victims are alone when the fire starts, many of these are elderly people. A large portion of the victims were not able to rescue themselves, because they were in a physically or mentally reduced condition. Such victims could be
- intoxicated by drugs or alcohol
- physically handicapped
- mentally disturbed
- very young children

Only 20 % of the fire victims in Norway in the period 1978-1992 were anticipated as able to evacuate themselves without assistance from others [3].

One interesting finding was that there are relatively few injuries from building fires. There are about three times as many fire injuries in Norway as fire fatalities. Of these, about 17 % are seriously injured [5]. This is in sharp contrast to traffic fatalities, where there are considerable more injures per fatality, and where a large portion of the injuries are serious, which leads to large personal suffering and high expenses for the community. Most fire injuries are caused by inhalation of smoke. There are few fire injuries among elderly people (aged 70 years or more) – only 7 % of fire injuries are registered in this group.

In Norway there will be about 3 fire injuries and 26 building fires per every recorded fire fatality. The corresponding numbers from Australia in the period 1989-1994 was 10 injuries and 143 building fires per fatality [7], i.e. a much smaller probability of fatalities and injuries per building fire than in Norway.

Elderly persons

Elderly persons resemble a large group of fire victims, and the proportion of this group compared to all fire deaths has been increasing. In the period 1985-1989, 30 % of the fire victims were older than 70 years. In the period 1990-1994, the ratio of elderly victims had increased to 33 %, and in the period 1995-1998, 35 % of victims in building fires were 70 years or older. This trend is shown in Figure 2.

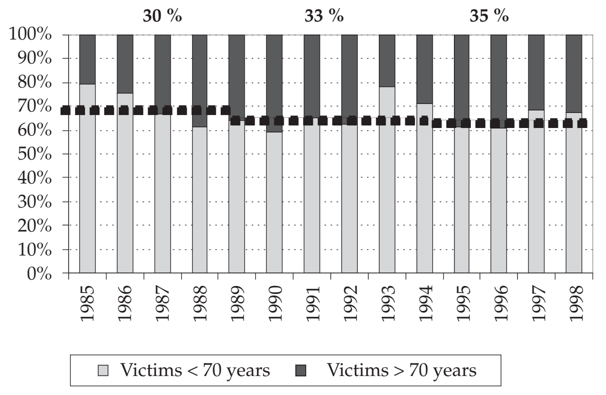

Figure 2. Fire victims aged 70 years or more, compared to fire victims less than 70 years of age in the period 1985-1998. The dashed line shows the averaged ratio of victims aged 70 years or more. This ratio was 30 % in the period 1985-89, 33 % in the period 1990-94 and 35 % in the period 1995-98 [5].

Persons intoxicated by alcohol or drugs

30 % of the fire victims in the period 1970-1979 were intoxicated by alcohol or drugs, 17 % of them heavily affected. The ratio of intoxicated fire victims in the period 1978-1992 has increased to 36 %, whereof 19 % were heavily affected. A larger proportion of fire victims in the larger cities are affected by drugs or alcohol than in less urban areas.

The proportion of intoxicated fire victims is large also in other countries, A Danish study of fire deaths in the period 1988-1993 reported that 62 % of the victims had alcohol in their blood [8]. In a study of fire deaths in London between 1996 and 2000, 40 % of the victims tested for the presence of alcohol were found to have high levels of alcohol in the blood [9].

Physically disabled persons

In Norway about 10-20 % of the fire victims are handicapped, and analyses in Sweden and Denmark also conclude that sick and disabled persons are highly represented among the fire victims [8, 9, 10].

Mentally unstable and suicidal persons

About 20 % of the fire victims in the period 1979-1992 were mentally disturbed to different degrees. The proportion of this group of victims had increased significantly compared to the period 1970-1979. It is reasonable to believe that some of these victims committed suicide; for some of the cases this was confirmed through statements from witnesses, in other cases the anticipation was based on strong indications.

Persons being alone when the fire started

Both the Norwegian and the Danish surveys show that a large part of the victims were close to the location where the fire started, and that they were alone. About 35-40 % of the victims were in the same room as the fire started in, and 14 % were in the next room [2, 3]. In about one third of the fires, only one person was present at fire start, and this person died. In Denmark, it was stated that 57 % of fire victims lived alone [8].

Sleeping children and young adults

An Australian project shows that most young children do not awake from the sound of smoke alarms [11], and therefore will need help to wake up in case of a fire. One cannot rely on that children will be alerted by a smoke alarm when they are at sleep. Another Australian project shows that many adults aged 18-24 years also would have problems by getting awake by the sound of a smoke alarm [12]. It has also been shown that many sleeping persons will hear the smoke alarm, but do not understand that the sound means that a fire is on, and will go back to sleep [13]. Smoke alarms, as tested in these projects, may therefore not function as the only means to warn people about a fire at night. To work properly as an alarm device, the alarms may need some modifications, e.g. of alarm signal (frequency, sound level, connection to other devices etc).

A survey was performed amongst 33 persons in Trondheim who had experienced a fire in their homes [14]. The majority of these people were alerted by sounds and smell from the fire. Only 6 of the 33 persons were first made conscious about the fire by the smoke alarms, and 5 of these 6 persons were asleep when the alarm sounded. A total of 14 persons were asleep. Sounds and smell from the fire were alerting more than half of the sleeping people in the analyzed fires. This is a strong indication that smoke alarms may have their greatest effect on alerting sleeping people, and that other signals than the smoke alarm will give most people awake a first awareness of the fire. There was no available information about function and installation of the smoke alarms in these fires.

Socioeconomic and geographical factors

Several studies, both international and Norwegian, have shown that the frequency of domestic fires are larger in some populations than in others. In a Norwegian study the following factors were identified as being significantly related to the frequency of domestic fires [15]:

- Number of disabled pensioners.
- Number of convicted persons.
- County (The three most northern counties in Norway have a fire frequency three times as high as in the rest of the country).
- High age (the fire frequency is higher for persons aged 75 years or more than for the rest of the population).

The latter finding implies that if a fire starts in an old person's dwelling, the probability to die is higher than if a fire starts in a younger person's home.

A Danish study shows that the fire frequency is higher for persons with low income than for other persons [16]. In block apartments where the median income is low, the fire frequency is 27 % higher than if income had no effect. On the other hand it was not possible to show that a high income will significantly lower the fire frequency.

An Australian study found a significant correlation between fire frequency and income, lodgers and areas with high age (65-85 years) [7].

1.3 ***Where do fatal building fires start?***

Fatal fires are most likely to happen in urban areas. An interesting finding in the Norwegian statistical material was that the proportion of fatal fires in urban areas had increased from 66 % in 1970-1979 to 73 % in 1987-1992.

In the period 1970-1992, 82 % of the fatal building fires in Norway took place in dwellings [3]. Of these dwelling fires, 60 % were in single family homes, 28 % in row houses and multi-family houses, and 12 % were fires in flats in apartment blocks. This means that fatal fires most often happen at home.

The three most likely places for a fatal fire to start are in the living room, in the bedroom and in the kitchen. However, there has been a change in the location of the point of fire origin in the Norwegian fatal fires over the 15 analyzed years. This is shown in Table 1 below.

Table 1. The location of the fire origin in fatal building fires in Norway in the periods 1970-1979 and 1987-1992 [3]

Location of fire origin	1970-1979	1987-1992
Bedroom	30 %	20 %
Kitchen	10 %	17 %
Living room	26 %	39 %

The numbers in Table 1 imply that there has been a shift towards that fatal fires are more likely to start in living rooms and kitchens, and that fires starting in bedrooms are less common than earlier. We believe that this is a consequence of a higher consciousness about the hazard of smoking in bed, combined with a general reduction in the number of smokers.

1.4 ***Where do the victims die?***

About one third of the victims in the Norwegian fatal fires in 1970-1992 were found in the same room as the point of fire origin. Most victims of the remaining 2/3 were found near the fire room, at the same floor of the building.

In the first 10 year of the period, 22 % of the victims were found in bed, while the same proportion was 12 % over the last six years from 1987 to 1992. This corresponds well to the finding that the bedroom as the point of fire origin decreased over the same period.

1.5 ***What kills people in building fires?***

Most fire victims, over 50-60 %, die of smoke, mainly because of carbon monoxide inhalation. This has been concluded through studies of fatal fires in several countries [2, 3, 8,].

In the Norwegian study, it was found that the number of mentally unstable persons had increased among the victims, and that there was a tendency to an increase in the number of victims where one suspected that suicide had caused the fire death. The increase in this number was from 1 % in the period 1978-1980 to 7 % in 1990-1992. The number of victims in this material is, however, small, so these results will only be valid as an indication.

2 The effectiveness of different detector principles

We know from statistical surveys, like the ones mentioned in references [2, 3], that people dying in fires suffer a lonely death.
Some fires start as smouldering fires and develop into flaming fires, while others are plain flaming fires from the very start. Based on the fire reports constituting the background for our statistical analyses, it is not easy to distinguish between these two types of fires. If the fire remains smouldering it easily shows on the fire scene. In a smouldering fire the combustion occurs on the surface of the fuel and the process is dependant on the diffusion of air to the combustion zone and diffusion of combustion products from the combustion zone.
A major discussion occurred in Norway in 1988 concerning the choice of principles by which the different domestic smoke alarms and detectors work. Some claimed that a lot of fires start as smouldering fires, and that the detector based on the ionic detection principle detect the smoke far too late, i.e. beyond fatality conditions. This allegation was taken seriously because 95 % of the already installed smoke detectors and alarms were based on the ionic principle and it was the most common fire protection measure in private homes. At that time it was furthermore discussed to require installation of at least one domestic smoke alarm in all private homes. This became mandatory in 1990.

A crucial question to answer was: How frequent are these smouldering fires that eventually turn into flaming fires, and thus are categorized as flaming fires? A smouldering fire could remain as such for a long period of time, creating life threatening conditions. Smouldering fires will create only a small rise in temperature and are soundless, which means that sleeping victims will not notice the fire and wake up. These victims could even be dead before the smouldering fire turned into the flaming phase. Since a lot of the analyzed fatal fires occurred while people were sleeping [2, 3] this problem had to be surveyed.

Since there is no way to establish the number of flaming fires which started as smouldering fires from the fire scene itself, at least not based on the normal fire reports from the police, this number had to be established in an indirect manner. One can anticipate that in a normal household, smouldering fires can occur in upholstered furniture and mattresses made of expanded polyurethane. To establish a smouldering fire in such a material, one has to start the fire by applying a glowing ignition source, like a burning cigarette. One cannot exclude other materials and/or ignition sources, but most of the smouldering fires will be in the category mentioned above. After going through the statistical material discussed in [2, 3], combining first ignited material and cigarettes, we established that the number of fatal smouldering fires will maximum be 25 % of the total number of fatal fires. This is considered to be a conservative number.

As a consequence of this discussion, SINTEF NBL decided to perform a series of tests using different detectors and smoke alarms in smouldering and flaming scenarios. Several different types of smoke detectors were tested together with heat detectors. These tests were performed in 1989 by SINTEF NBL together with detector producers, insurance companies and Norwegian Fire Protection Association [18]. The test room was arranged like a patient room in a hospital with normal bedding components with no addition of flame retardants. The registered moments for alarm were evaluated against criteria for safe occupancy conditions associated with CO- concentrations, visibility and temperatures. The safe occupancy criteria were based on the recent year's research results. Unsafe occupancy concerning CO-concentrations is considered to be beyond the accumulated dose of CO (measured in ppm·min) leading to incapacitation. Some of the test results are shown in Figure 3, Figure 4 and Figure 5 below.

In the tests with smouldering fires critical conditions were reached after 5-6000 seconds after fire start. Both the optical smoke alarms and detectors responded before life threatening conditions were reached. The ionic based alarms and detectors did not give adequate protection in case of smouldering fires in these tests.

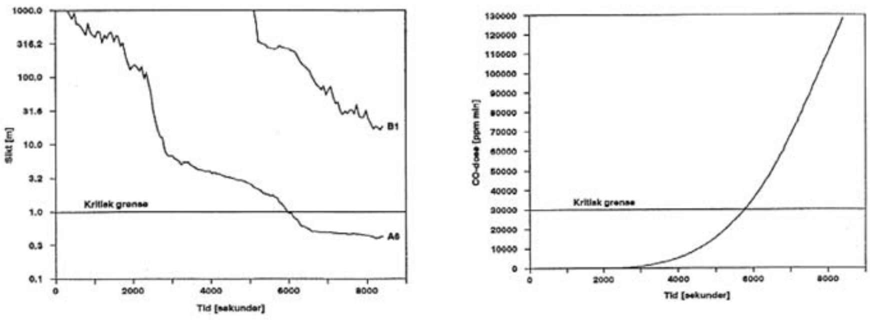

Figure 3. Smouldering fire development. Left diagram: reduction in visibility [m] in the fire room (A6) and in the adjacent room (B1) versus time [s]. The critical limit for visibility, defined as 1.0 m, is indicated. Right diagram: accumulated CO-dose [ppm·min] in the fire room versus time. The critical limit for CO-dose, defined as 30 000 ppm·min, is indicated.

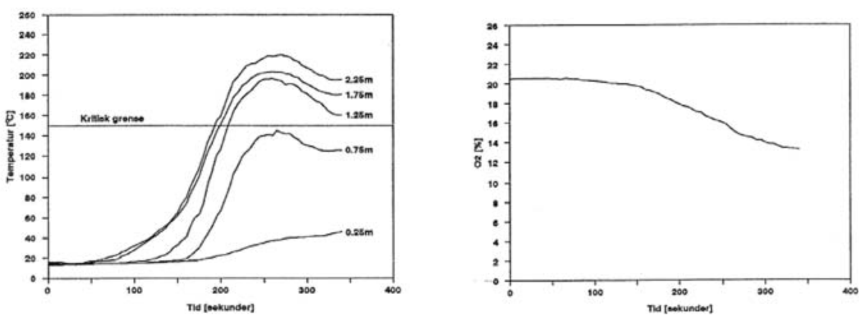

Figure 4. Flaming fire development. Left diagram: temperature [˚C] measured at different levels above the floor versus time. The critical temperature limit, defined as 150 ˚C, is indicated.
Right diagram: Oxygen concentration [Vol%] at ceiling level in the fire room versus time.

In the flaming fires the critical temperatures in the smoke layer were reached 200-240 seconds after the fire start. The alarms and detectors based on the ionic principle reacted slightly faster than the alarms and detectors of the optical type. The differences are considered to be marginal. These results are in accordance with results from a recent extensive project at NIST in US, where several smoke detectors were tested in a variety of fire conditions [19]. Fire tests in domestic bedrooms showed times to smoke detector response in the magnitude of what was experienced in the SINTEF NBL tests in the simulated patient room.

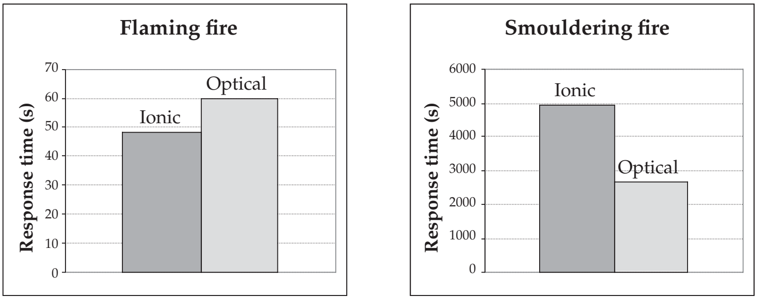

Figure 5. Response time [s] for optical and ionic smoke alarms in a flaming fire and in a smouldering fire. The smoke alarms were located in the ceiling in the fire room. Note the large difference in time scales for response time in the two types of fire.

From these test results one could clearly conclude that smoke alarms in dwellings preferably should be based on the optical detector principle, if only one type should be applied.

At the end of the 1980's 95 % of the domestic smoke alarms were based on the ionic principle. Considering this information, and the fact that smouldering fires are likely to start as a result of ignition by glowing cigarettes, one could state that people should be sufficiently safe if one could avoid such fire starting conditions. This implies that one first of all should avoid that people are smoking in their beds.

However - all this information, recommendations and finally official prescriptions will most likely not reach the individuals of the population most threatened by domestic fires, being elderly single alcoholised men, as shown in [2, 3].

3 Time to flashover and available time for evacuation

SINTEF NBL performed a series of analyses of occurred fires over the period 1978-82 to retrieve data that could be used as a basis for revision of prescriptions [20, 21]. One of the factors studied was the different times to flashover in the rooms of fire origin. The rooms or occupancies were of different sizes and involved different activities. Half the number of fires involved flashover times less than 10 minutes. Smaller rooms, like patient rooms in hospitals or living rooms in private homes, gave flashover times in the order of 6 minutes. Later investigations of occurred fires reveal that the flashover times for dwellings, hospital rooms and the like, after the flaming stage is reached, are 5-10 minutes. The majority of these flashover times are closer to 5 than 10 minutes.

Among the above mentioned analyses performed by SINTEF NBL in 1978-82, one study concentrated on hospital fires only [22]. 4 actual hospital fires occurring in the project period were closely analysed and the project team issued a comparison of the findings in Norway with results from international studies [23]. The 4 actual fires included 2 incidents that were classified as catastrophes (i.e. resulting in more than four fatalities). The following conclusions could be drawn from the studies of the hospital fires concerning the actual fire risk for hospitals:

- The three main factors of importance for the fire safety of the patients are alarm, actions taken by the personnel, and the reaction-to-fire properties of the bedding components or other interior materials. The actions taken by the personnel include fighting the initial fire, assist evacuation and closing doors to the fire room.
- A critical situation can occur in a patient room only three minutes after bedding components without any flame retardants have been ignited by a small flame. A critical situation means a situation that is not controllable by the personnel.
- The smoke spread potential represented by an open door is paramount and should attract much more attention than it has done (this is unfortunately the case even today in 2005). Fire protection and preparedness is concentrating on smoke spread potential of ventilation ducts, dampers when ducts are penetrating walls, and the procedure to stop the ventilation system in the case of fire. Stopping the ventilation system was a major mistake in the case of the fire on the passenger ship “Scandinavian Star” 7th April 1990, where 158 persons died [24]. As long as the air inlet lines are separated from the air outlet lines it is important to let the ventilation system run to avoid spread through the system by natural pressure differences.
- An automatic detection and alarm system alone is not giving any guarantee for the patient’s safety. This must be closely linked to the personnel’s possibilities to act.
- The difference in response time between heat detectors and smoke detectors is of vital importance to the patients’ safety when bedding components without any flame retardants are used.
- Quick and adequate actions from the personnel are heavily dependant on the instructions and training given to the personnel.

All these findings from the analyses of the unfortunate hospital fires led to changes in the prescriptions, making it mandatory to install automatic smoke detection systems in hospitals with more than ten beds. It furthermore led to a major campaign throughout the country to instruct and train hospital personnel in how to meat a start fire and manage to control it.

SINTEF NBL performed a cost-benefit study of the public fire brigades in 1988-89 [25]. This study showed that the fire brigades usually arrived at the fire scene at the time when the fire room or the building reached flashover, or shortly after this moment. This means that the fire brigades in many cases will arrive too late to be able to rescue persons from the fire room, and that measures against fire with a fast response time are necessary to increase the human safety.

From all the above mentioned statistical analyses, case based studies and cost-benefit studies, one conclusion concerning human safety is evident: *The major difference between failure or success for saving human lives lays in the possibility of the occupants to have an early responding, audible and understandable alarm, and the possibility to perform quick and adequate actions of fire fighting and assisted evacuation.*

Based on these findings and following expert panel discussions, the Norwegian fire prescriptions were radically changed. From 1990 it was mandatory to have smoke alarms (one battery driven smoke alarm as a minimum) and hand held extinguishing units (portable powder extinguishers or water hoses) in every dwelling, both in existing as well as in new units [26]. At that time this was a very unusual claim to include in public prescriptions. As shown in [5] this was lucrative in terms of saved lives compared with the total installation costs for all the dwelling units in Norway.

In a survey performed by NFPA in the US, the available time to escape was analysed concerning how it would affect human safety in home fires [27]. One conclusion was that roughly half of the fire deaths and two-thirds of the injuries in dwelling fires in the US could be prevented if the times to escape were sufficiently lengthened.
Smoke alarm was identified as a necessary measure for saving most sleeping victims.

4 Many countries require smoke detectors in dwellings

Although many countries have had no legislation regarding installation of domestic smoke alarms, the prevalence of such alarms has been quite high for many years. National information campaigns over the last have been the main reason for this widespread use of smoke alarms. Some countries will not accept installation of ionization smoke detectors, because the radio active sources in the detectors represent a large problem for waste treatment when old smoke alarms are discarded. Below, requirements in some nations are briefly presented.

Norway: Smoke alarms have been required in both new and existing residential buildings since 1991. This requirement also includes holiday homes and cottages. At least one approved smoke alarm shall be installed in each dwelling, and shall be heard in all bedrooms when the doors are closed [26]. There are no specific requirements to which type of detector that should be installed, or to the type of power supply system, but recommendations on different solutions are given in the guidelines to the regulations [28].

Denmark: 1st of December 2004 the new fire safety regulations in the building regulations for small buildings came into force. The regulations are applicable for single family houses with a maximum of two floors and a basement. One of the new requirements is the prescription of a smoke alarm system for each dwelling. The system shall be coupled to the mains, and shall be equipped with a battery backup system [29].

Sweden: All buildings shall be equipped with safety measures that prevents fire from starting and developing, and that restrict fire damage [30]. On this background, the Swedish Rescue Services Agency issued a general recommendation on installation of smoke alarms in all residential buildings in 2004 [31]. At least one functioning alarm should be installed in each floor, and precautions to ensure a continuous power supply are recommended.

Finland: All residences in Finland, both existing and new (including summer cottages and other holiday houses), must be equipped with fire detectors [32]. This decree came into force 1 September 1999, and the detectors had to be installed within a year. There must be at least one detector in each storey, and it must be kept in working order (the batteries must be functional etc.). The occupant of the residence is responsible for the installation and maintenance. Battery is the required power source. If the detector is wire operated, it must be provided with a battery backup.

United Kingdom: According to the Building regulations from 2000, dwellings shall be provided with devices for the early warning of fire [33]. A general recommendation about placing smoke alarms in connection with bedrooms, and installing at least one detector in each floor is given. Smoke alarms can be wired or battery operated.

The Netherlands: Smoke detectors have been required in new dwellings in the Netherlands since 2003. Detectors shall be of the non-ionic type, and shall be coupled to the electrical mains system [34]. There are no requirements for smoke alarms in existing dwellings.

The United States: Smoke detectors have been increasingly common in domestic households over the last three decades, and it is estimated that 93, 6 % of homes across the US had a smoke alarm installed in 1995 [35], and at least 95 % in 2000 [19]. The high prevalence is a result of different strategies: public education, legislations, improved technology and smoke-alarm-giveaway programs. Several states in the US have legislation requiring domestic smoke alarms.

5 How many homes have smoke alarms installed? How many alarms work?

Nearly all Norwegian dwellings, i.e. more than 97 %, have smoke alarms installed. Surveys have shown, however, that only 60-80 % of these smoke alarms would function as required in a fire [5]. There are less smoke alarms, and also less working alarms, in dwellings where there have been a fire. In dwellings where there has been a fatal fire, the number of functioning smoke detectors is even lower.

In a survey of statistical information from 365 Norwegian fatal fires in the period 1997-2003, where a total of 420 victims died [36], it was found that
• 25 % of the dwellings had a working smoke alarm installed
• 21 % had no smoke alarm or a non-functioning smoke alarm installed
• For 38 % there was no information available whether a smoke alarm was installed or not.

In a Swedish survey it was found that a working smoke alarm was absent in 75 % of fatal fires in Sweden in 2002 [37]. In Norway dwellings in row houses are best covered by smoke alarms [5]. Single-family homes have a coverage near the national average for Norway, while flats in block buildings have the lowest number of smoke alarms installed. Holiday homes are also poorly covered.

In all the Nordic countries there are most smoke alarms installed in single-family homes, and fewer in flats. Information campaigns have resulted in the high level of smoke detectors in Sweden, Denmark and Finland. It looks like, however, that Norway, through prescriptions, has obtained a higher degree of smoke alarm coverage than the other Nordic countries. Denmark and Sweden have not had any requirements for installation of this equipment before recently.

6 Is there room for improvements?

It is impossible to state the exact number of lives that smoke detectors have saved. The falling trend in number of fatalities in building fires is shown in Figure 6. This figure shows that the average number of fire fatalities per million inhabitants has decreased from 16.4 in the end of the 1980's to 14.1 in the end of the 1990's. Related to a Norwegian population of about 4.5 million people, this means that approximately 10 lives are saved every year compared to the number of fatalities in the late 1980's.

SINTEF NBL has performed a study [5, 6] concerning the cost–benefit effects of these requirements. This study shows that the requirements are cost effective. A rough estimate on the cost-effectiveness is based on the following assumptions:
• 2 smoke detectors per housing unit with 10 years of operating time
• 2 batteries per housing unit per year
• 2 millions housing units
• a statistic life is worth 18 millions NOK (2000-value)

Based on these premises the yearly cost is estimated to be 120 millions NOK, while the benefit per year is estimated to be 180 millions NOK. This gives a net annual profit of 60 millions NOK, or expressed as a benefit-to-cost ratio of 1.5: 1.

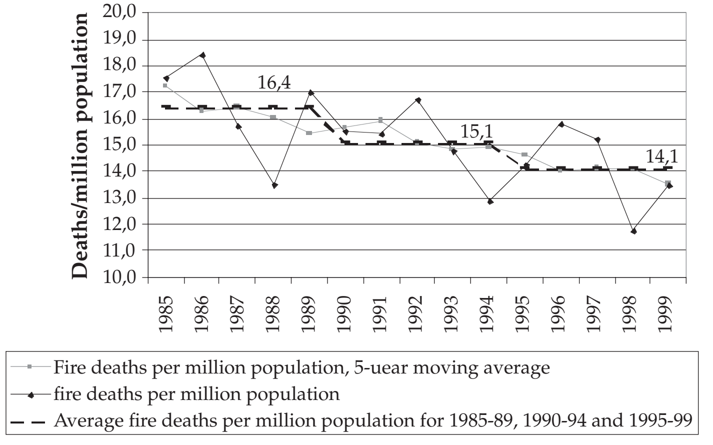

Figure 6. 5-years moving average of fire deaths per million population in Norway, yearly number of fire deaths per million inhabitants and the average number of fire deaths per million inhabitants for 1985-89, 1990-94 and 1995-99

This estimate only includes the benefit of saved lives. In addition smoke alarms will limit material losses by detecting fires at an early stage.

Reports from the Norwegian fire brigades show that mobile fire extinguishing equipment in dwellings prevent fire spread in 15 % of the domestic fires every year. We have no statistical information that indicates the potential material loss if the fire extinguishing equipment had not prevented the fire from spreading, but we could assume that fire-extinguishing equipment reduces the insurance companies' compensation of fire losses with 15 % per year. The estimate is based on the following assumptions:

- One portable extinguisher per housing unit with 10 years of operating time.
- 2 millions housing units.
- Compensation from the insurance companies for material losses in dwelling fires per year is 1 500 millions NOK (in1999) [38].

The resulting cost per year is estimated to be 100 millions NOK, while the annual benefit is estimated to be 225 millions NOK. The resulting benefit-to-cost ratio will then be approximately 2:1.

Data and experience from domestic fires over the last 10 years show that the coverage and function of smoke alarms imply an improvement potential. Improvements will arise from the following main actions:

• *Secure the power supply*

The main reason that smoke alarms do not function is missing or flat batteries. By connecting the smoke alarms to the mains or by using long-life batteries (10 years operating time), the probability that the smoke alarm will function increases considerably. The need to change battery will decrease, which will be beneficial for some groups of persons where this may be a problematic operation (for instance elderly persons).

• *Connect the smoke alarms in series*

Install more than one smoke alarm and connect them in series. This will secure an early detection and warning of fire. Full-scale experiments indicate that approximately 2 minutes of extra evacuation time can be achieved if more smoke alarms are installed, instead of having one smoke detector in each dwelling [7].

• *Improve follow-up and inspection*

Higher priority should be given to follow-up and inspection of the fire safety in dwellings. A possible solution is that the fire brigade, chimneysweepers or insurance companies carry out inspections to check that the required equipment is properly installed and that it functions. This may, however, be perceived as unnecessary monitoring and guardianship. Another solution is that every house owner has to document that he or someone else has verified the equipment.

• *Special actions for elderly persons and other groups at risk*

We recommend inspection programs to be carried out to assist elderly persons and disabled persons to maintain the smoke alarms.

Primarily, smoke alarms will help persons that are able to evacuate without assistance. Only 20-30% (approximately 15-20 persons) of the Norwegian fire victims belonged to this group before the requirements came into force [2, 3]. We have assumed that some of the victims categorised with "unknown condition" in the SINTEF NBL analyses actually would be self-reliant. An established effect of approximately 10 persons saved per year is already demonstrated through our analysis. That indicates that the maximal yearly potential for further reduction in the number of fire deaths in Norway is approximately 10 persons, based on the prerequisite that every Norwegian household have smoke detectors that function in case of a fire.

7 Conclusive remarks

The SINTEF NBL studies [2, 3, 20, 22] clearly show that 70-80 % of the fatalities occur in dwelling units; i.e. private homes and cottages, and that people die one by one. Traditionally, building prescriptions and building codes are not addressing measures or requirements for protection of human lives as they are normally threatened in fires. Prescriptions and codes will in the first place protect against catastrophic fires, and will protect third parties from damages from the buildings on fire.

The requirements in the fire prescriptions of 1990 [26] are, however, addressing the daily fire threat to people by requiring at least one smoke alarm and a hand held extinguisher in every dwelling unit. Norway has a population of approximately 4.6 million people per January 2005. This means that the demonstrated effect from installation of smoke alarms and hand held extinguishers is 2.2 lives per million inhabitants. The estimated full potential of these measures against fire is estimated to be 4.4 saved lives per million persons.

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