Smoke Alarms in Dwellings:  
Occupant Safety Through Timely Activation and Effective Notification  

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Abstract

The time of smoke detection and loudness of the alarm sound received by occupants largely determine the effectiveness of smoke alarms in dwellings. This paper reports on research that measured both of these for smoke alarms in the room of fire origin, hallways and in other rooms to help determine the benefits of smoke alarms in rooms rather than hallways, in more rooms than currently required, and interconnected rather than unconnected alarms. The results demonstrated significant benefits would be obtained with interconnected alarms in all rooms – on average much faster detection and much more effective warning, particularly for “at risk” people. It is expected that adoption of interconnected smoke alarms in all rooms of dwellings would result in significantly reduced fire fatalities.

Introduction

Determining the most appropriate locations for smoke alarms in dwellings requires consideration of many factors affecting the time at which smoke is detected and the likelihood of effective notification of occupants, the latter strongly influenced by the loudness of the sound received by each occupant and the condition and characteristics of the occupants.

In this research the loudness of the received alarm sound in the rooms in real houses and the effect of the smoke alarm location on smoke alarm activation time using ionization, photoelectric and dual (ionization plus photoelectric) smoke alarms were determined experimentally. This was followed by an examination of the dwelling fire fatalities that occurred in Victoria, Australia between 1998 and 2006. This and the experimental results were used as a basis for estimating the change in fatalities that might occur if smoke alarms in every room or interconnected smoke alarms in every room were required in Australia by changed building regulations. In addition the ignition locations (room or space of fire origin) of the fatal dwelling fires and the locations of the occupants at the time of ignition were used to determine the most appropriate locations of smoke alarms if it were to be deemed that placing them in every room is too stringent a requirement [1].

Methodology

The smoke detection measurements were undertaken in full scale cardboard models of four houses. Seven materials were burned (three smouldered, four produced flaming) in each room (the RFO – room of fire origin) and the time of activation of the smoke alarms in each room and hallway recorded. The materials burned and form of combustion were based on those specified in ISO/TS 7240-9 (2006) “Test fires for fire detectors” [2]. The smoke sources were braided cotton wick (which smouldered producing voluminous whitish smoke), n-heptane (very black
smoke), decalin (much very black smoke), a wood crib (light grey to white smoke), dried wood sticks (pinus radiata) on an electric hotplate (light grey smoke), cotton towel heated by an electric heating element (light grey smoke) and three sheets of polyurethane foam (much black sooty smoke). In all of the reported tests the windows were shut and room doors open. The smoke alarms were fitted on the ceiling near the centre of each room and in each hallway. The smoke alarms were from two manufacturers and were purchased from large hardware stores. Each room was fitted with two ionization alarms (called I1 and I2), two photoelectric alarms (P1 and P2) and one dual alarm (D2). In hallways the dual alarm was omitted. The smoke alarms were cleaned regularly and very little variation in alarm response was observed during the testing program.

The level of sound (in dBA) resulting from smoke alarm sounds emitted in each room of five real, currently occupied houses was measured with various combinations of room doors open and closed. (Four of these houses were modelled in the smoke tests described above.) Two sounds at two set levels (85 and 105 dBA when measured 1.0 m directly below the speaker) were emitted from positions close to the middle of the ceiling in each room and hallway (the RSO - room of sound origin). The sounds used were the ~3100 Hz sound currently used in Australia in domestic smoke alarms and the 520 Hz square wave sound used in the testing of the ability of these and other sounds to arouse various groups of sleeping people from deep sleep [3-15]. The sound levels in the rooms were measured in positions diagonally opposite the room door at approximately pillow height using recently calibrated Lutron SI-4001 sound meters with the settings on “slow response” and “maximum hold”. The ambient sound level (without the alarm sound) in most rooms was generally in the range 35-40 dBA.

**Results**

In many of the smoke detection tests some of the smoke alarms did not activate but this does not mean they were faulty as no alarms were found to consistently fail to operate. In the RFOs the dual alarms always operated in the 163 relevant tests and only one of the two ionization alarms did not operate but only in one of 174 tests. The photoelectric alarms were not as successful as they operated in only 90% of the 174 tests. However, in terms of alarm operation, the alarm location was more significant than the type of alarm. In the hallway in the single story houses the proportion that operated was about 96% for the ionization alarms in 128 tests compared with 80% for the photoelectric alarms. In 46 tests in the two story house about 77% of ionization and about 55% of photoelectric alarms operated in the second story but in the lower story the ionization alarms operated in only 50% and the photoelectric alarms in about 52% of tests. Thus even when the RFO door was open (as it was in all of these tests) there was a significant drop in the percentage of alarms that operated in hallways or other rooms compared with those in the RFO.

In the following it should be remembered that only the alarms that operated are included. The alarms that did not operate either would never have operated in these tests, or would have taken considerably longer to operate than the slowest operating alarm, as monitoring for alarm operation was continued for substantial periods after the last alarm operated. The median time of operation of smoke alarms that operated in the RFOs, hallways and other rooms show that the
hallway activation was often considerably delayed compared with that in the RFO, and that activation in the other rooms was usually delayed even more [1, 16].

The median times of operation for smoke alarms in the RFOs were 97, 76, 175 and 202 seconds for I1, I2, P1 and P2 respectively. In comparison, the median times of operation in hallways were 285, 250, 336 and 338 seconds respectively. It can be seen that this represents a very significant delay in each case. These delays were with room doors open – much greater delays would have occurred (or the alarms would not have operated at all) if the RFO door was closed. Greater delays were generally experienced when the hallways were not on the same story.

As would be expected, when the other rooms are considered the delays are generally greater and this was reflected in the median times of operation in the other rooms: 322, 316, 477, 482 and 413 seconds for I1, I2, P1, P2, and D2 respectively.

The measured sound levels in rooms due to sounds emitted in hallways were significantly lower than the emitted sound level. The median sound levels in rooms with the room door closed were 44.8, 62.3, 52.7 and 72.4 dBA for the 3100/85, 3100/105, 520/85 and 520/105 sound type/level combinations explained above [1,16,17]. With the room door open the levels were obviously higher: the median measured levels were 57.2, 75.7, 64.2 and 84.0 dBA respectively.

When the sounds were emitted in rooms rather than hallways the sound levels in the other rooms were lower: with both room doors closed the respective sound levels were 38.9, 44.8, 39.9 and 47.3 dBA. In many cases the measured sound level was similar to the measured ambient sound level. When both the RSO and other room doors were open the respective sound levels were 46.5, 67.3, 52.6 and 71.1 dBA.

The measured sound levels with only one or other of the RFO and other room doors closed were obviously between these levels.

Discussion

The measurements of sound levels showed that effective notification of occupants (based on a received sound level of at least 75 dBA, but louder would obviously be preferable as discussed elsewhere [17]) can only be achieved with smoke alarms in every room. Otherwise the sound level in many locations is very likely to be too low to achieve effective notification, particularly of sleeping people, but also of people who are awake but with imperfect hearing. The lower frequency (520 Hz square wave) alarm sound was found to be more effective but would still not guarantee an adequate sound level without alarms in each room.

The smoke alarm activation time measurements showed that in dwellings rapid detection of smoke can only be achieved with smoke alarms in every room. The time to detection (given a particular smoke source) was found to be particularly influenced by doors (open/closed), the characteristics of the RFO and the characteristics and location of the room or hallway in which the alarm was located. The type of detector had a lesser effect. The type and form of the material that was burning also strongly influenced the time to detection. Overall, with all other factors being equal, there was a considerable delay in activation times for alarms not in the RFO compared to those in the RFO.
Estimated Effect of Interconnected Smoke Alarms

The effectiveness of any change to requirements for smoke alarms in dwellings can only be estimated if there is detailed knowledge of why people currently die in dwelling fires. Based on analysis of each recent fatality it is possible to assess whether proposed changes would be likely to lead to a better outcome. The effectiveness then is the overall reduction in fatalities that would be expected to occur in similar circumstances but with the proposed new requirements for smoke alarms.

This was undertaken by a detailed analysis of coronial records relating to 128 dwelling fire fatalities. Eighteen of the fatalities occurred in eight multiple fatality fires. Nine of these fatalities were children. Alcohol was recorded in the bloodstream of five of the 9 deceased adults. Locked doors impeded escape in two of the eight fires, fire growth was too rapid to allow escape and/or the fire was between the occupants and the exit in two of the fires, one of the fatalities was a baby and therefore unable to move, and mobility problems may have impeded the escape of two adults and several of the younger children.

Seventy-four of the fatalities (none children) were the only fatality in the fire and were alone in the dwelling at the time of the fire. Of these 59 were tested for blood alcohol content (BAC) and/or drugs and of those tested 76% had a BAC ≥ 0.07 and/or drugs. In 37 of these cases, where the presence and/or activation of smoke alarms is known, 27% had none present, about 35% had working smoke alarms (not all in the RFO) and about 38% had smoke alarms but they did not operate. In the known cases, 74% responded to the fire and were “active” in some way during the fire but in 33 of the 74 fires there was a physical factor that adversely affected escape and/or survival (clothing burning, fire development too rapid or between the casualty and the exit, or a locked door impeded escape).

In the remaining 36 fires there was also a single fatality but the fatally injured person (8 of them a child) was not alone in the dwelling at the time of the fire. Twenty-four of the adults were tested for BAC and/or drugs with 42% of those tested found to have a BAC ≥ 0.11 and/or drugs. The smoke alarm situation was known in 25 of these fires with 28% having no smoke alarm present in the dwelling. In 32% of fires with known smoke alarm situation a person died despite smoke alarms operating, in about 28% smoke alarms were present but did not operate and in about 40% there were no smoke alarms present. Overall, 24 people (89% of known) responded to the fire and were “active” in some way during the fire. In 10 of the fires there was some physical impediment to the ability of the occupant to remain alive (2 clothing burning, one development of the fire too rapid, one the fire between the casualty and the exit and in some cases a locked door impeded escape). Thus about 75% (of known) fatally injured occupants responded to the fire.

It can be seen from this summary that many of the occupants had characteristics that were likely to have severely affected their ability to respond to low level alarm sounds (we consider them to be particularly “at risk”), but many may have been aided by very much louder and/or earlier alarms.
We have undertaken a detailed risk based review of these fatalities and, in our opinion, with smoke alarms in every room (when compared with smoke alarms just in hallways which is currently the usual practice in Australia [18]) there would be up to 30% fewer fatalities. Again in our opinion, the use of interconnected smoke alarms in every room could result in about 50% fewer fatalities.

Because most fires and the people adversely affected by them are in these rooms about 90% of the predicted benefit would be obtained if interconnected smoke alarms were placed in bedrooms, lounge rooms and kitchens rather than in all rooms.

Conclusion

Based on the experimental results discussed above early detection and notification is best achieved by interconnected smoke alarms in every room. Unconnected alarms and alarms just in hallways or alarms just in hallways and bedrooms are obviously sub-optimal as they lead to delays in alarm activation and alarm sounds at levels well below those that may be reasonably expected to be effective in notifying many occupants, particularly if they are asleep.

The Victorian coronial records briefly summarised above suggested that interconnected smoke alarms in every room (when compared with smoke alarms just in hallways) may be expected to lead to up to about 50% fewer fatalities in dwelling fires in Australia. About 90% of this predicted benefit would be obtained if interconnected smoke alarms were placed in bedrooms, lounge rooms and kitchens rather than in all rooms because the relevant fires and the people adversely affected by them are very largely in these rooms.

References

1. Thomas I and Bruck D (2010) Smoke Alarms in Dwellings: Timely Activation and Effective Notification, Centre for Environmental Safety and Risk Engineering, Victoria University, Melbourne Australia
17. Thomas I and Bruck D (2010) Smoke alarm sound levels in Australian houses, 8th Asia-Oceania Symposium on Fire Science and Technology, 7-9 December, Melbourne, Australia