RESIDENTIAL SPRINKLERS
PROVIDING LIFE SAFETY AND LOWERING COSTS

Fredrik Nystedt, BSc FPE
Department of Fire Safety Eng., Lund University
PO Box 118, SE 221 00 Lund, Sweden
http://www.brand.lth.se/english/
e-mail: fredrik.nystedt@brand.lth.se

SUMMARY

Residential sprinklers provide excellent life saving features. A national project in Sweden has been initiated in order to develop guidelines and engineering principles for the use of residential sprinkler systems. This paper gives a brief summary of one of the parts of the projects, namely a study on risk evaluation and cost effectiveness analysis. A hand-calculation fire development model has been developed to aid engineered design. The model treats uncertainties and variability explicitly by employing Monte Carlo simulation. This model has been applied to a fictive apartment and the results states that residential sprinklers provide increased possibilities to escape in the event of fire. Future research will link the fire development model to a model considering human behaviour in fire.

INTRODUCTION

Currently, in Sweden very few sprinkler systems are installed in residential buildings. This despite the fact that sprinklers according to US investigations could lower the death risk due to fire by eighty percent. A national project was recently established with the main objective to make the use of residential sprinklers attractive to both the builder and to the house owner. The project involves over twenty industrial companies, researchers from Lund University, the Swedish National Testing and Research Institute and the Swedish Institute for Wood Technology Research, who will try to make residential sprinkler an attractive and low cost life saving safety measure. The project involves a risk evaluation, a cost effectiveness analysis, installation and maintenance instructions and guidance on fire safety tradeoffs.

The analyses of risk and cost benefit are of great interest as they focus on the individuals' rather than having the societal perspective. Developed recommendations and guidelines will be risk-informed with a sound scientific background. This paper will describe the up-to-date findings of the project.

FIRE FATALITIES

Statistics on death fires could provide useful knowledge to prevent future accidents. In Sweden there are app. 80 people dying in residential fires per year. Table 1 outlines the distribution of firer fatalities in residential buildings in 2000[1].

Table 1. Distribution of death fires in different types of residential buildings.

Dwelling type	Number of fires	Number of fatalities
Multifamily	33	33
One-family	29	30
Two-family	1	1
Cabins	4	4
Elderly homes	15	15
Sum	82	83

It is very rare that a dwelling fire results in more than one fatality. Therefore it is possible to focus on the individual risk when evaluating the safety level. A Japanese study performed by Sekizawa[2] derived some interesting conclusions concerning death fires. 48% of the fatalities were over 65 years old and 9% where younger than 6 years old. Disabled people at the age of 65 or more are exposed to 40 times higher risk of dying in fires than the average population. More than 70% have difficulties in performing an evacuation. 50% are alone when the fire breaks out.

Death fires often starts in bedrooms, living rooms or in the kitchen. Common fire causes are smoking, malfunctioning electrical installations and the misuse of heating devices. The most dominating death cause is intoxication by carbon monoxide[3]. Many fatalities could have been avoided if fundamental fire safety measures would have been undertaken. According to a Swedish study[4] covering 1983-1994, only 6% of death fires had an operating smoke alarm. Similar experience has been documented in North America. The effect of fire safety measures could be illustrated by the ratio between injury and death. Ruegg et al[5] states that the ratio is 3 to 1 for no extra safety measures, 6 to 1 if smoke alarm is present and 10 to 1 if a residential sprinkler system is employed. The study performed by Ruegg et al also states that a residential sprinkler system reduces the risk of dying in fire by 82%. If only the smoke alarm would have present the reduction would have been 48%. According to the Swedish statistics[1] app. half of the victims had initiated evacuation, about 25% were closely involved in the initial fire (burning clothes, etc.) This information states that the most effective life-saving measure is probably the smoke detector. A residential sprinkler will only cover up for those not able to perform an evacuation despite their possible awareness of the fire cues.

RESIDENTIAL SPRINKLER SYSTEMS

The residential sprinkler concept was developed in the USA in the beginning of the 1970s. The purpose was to reduce the great number of fire fatalities that occurred every year. Residential sprinkler systems should fulfil the following criteria; flashover should not occur, it should be possible to perform evacuation and a limited water supply should be used to fulfil the two first criteria. The fundamental principles behind the development of the NFPA13D/R are listed below. The cost is an important factor. It was necessary to develop a system that had high efficiency to a considerably lower cost. This lead to a system with lower reliability and greater restrictions than what a traditional sprinkler systems. Life safety was the key issue. Property protection is secondary. The system should be designed to maintain tenable conditions for escape during the early stage of the fire. A limited 10-minute water supply was acceptable. The installation procedure and the materials used should be compatible with existing building techniques. Fire statistics was used to derive areas where sprinklers could be left out.

International experience shows a clear reduction in installation costs, property losses and fire fatalities when a demand on residential sprinkler systems has been adopted in the building code[6]. There are a number of issues that affect the sprinkler system's reliability. Frequently causes of failure are improper design, absence of water source and malfunctioning sprinkler heads. NFPA states that residential sprinklers fail to operate properly in about 8% of the cases. Lacks of maintenance or incorrect installation are major causes of error.

A number of design freedoms are given to the developer, builder and owner when a residential sprinkler system is installed. These design freedoms provides a more flexible use of land, the architectural design of the building and some costs savings.

RESIDENTIAL FIRES

Gomberg performed in 1982 a study[7] were residential fires were categorized into nine major scenarios. These scenarios were classified by start places and development. Possible starting places are outside the resident, in a hidden space inside the building or an open fire in an enclosure. The fire development category was broken down into non-flaming fires, flaming fires and fires with very fast growth. Figure 1 gives an illustration of the fire development[8].

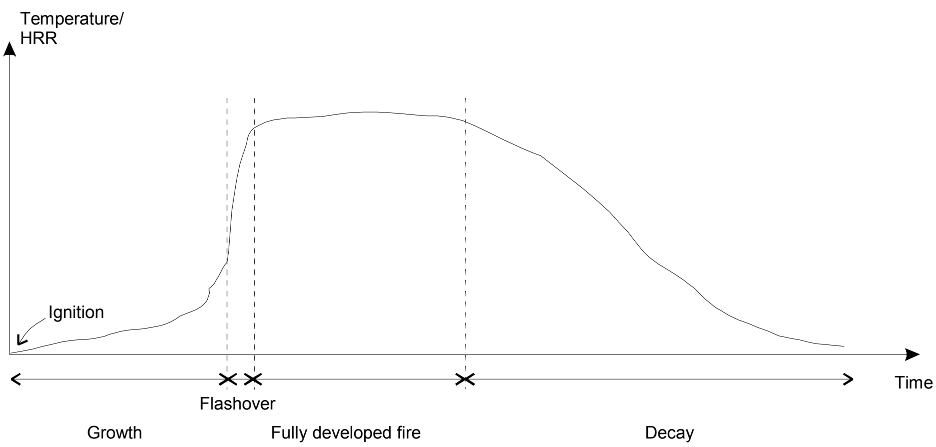

Figure 1. Illustration of the fire development in an enclosure[11].

Purser[3] outlines major causes of injury and death in fires. These are the presence of heat, toxic products and smoke, oxygen depletion and panic reactions. Fire statistics states the inhalation of toxic compounds is the far most common cause of death in residential fires.

FIRE DEVELOPMENT CALCULATIONS

In order to produce an aid for the engineer to perform quantitative analyses of sprinkler efficiency a model for fire development calculations has been developed. The model consist of a number of hand-calculation expressions on heat release rate, enclosure temperature and smoke filling, detector activation, sprinkler efficiency, dose-response, etc. The model should comply with the following requirements. It should be simple and transparent in its design. It should be possible to treat variability and uncertainty explicitly. It should be possible to evaluate the consequence on the safety level when different design freedoms or tradeoffs are given.

In order to fulfil the requirement a spreadsheet model has been developed which could be used with add-in risk analysis software. The output from the model is a probability distribution function of the time until incapacitation or death occurs. The model consists of a number of sub models illustrated in Figure 2.

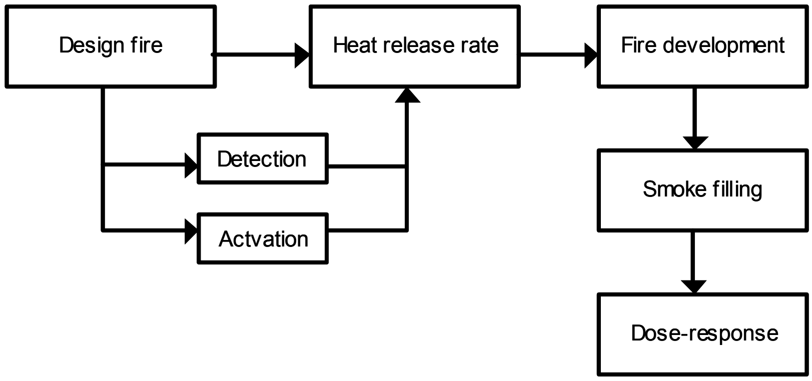

Figure 2. Outline of model.

The design fire is based on the fuel load in the enclosure. The design fire relates to growth characteristics, maximum heat release rate and yield. It is possible to include furniture, surface finishes and adjacent objects. The design fire is represented by its heat release curve. The heat release of the design fire is later modified to accomplish for the presence of limited ventilation and a suppression system. In the sub model for fire development the fuel mass burning rate, the smoke temperature and the smoke transport is assessed. Sub models for detection and activation calculated when the smoke alarm and the sprinkler system respond to the fire cues. Smoke yield, detector type, heat release rate and detector spacing are important data. The effect of the fire on humans is assessed in the dose-response model.

Uncertainty and variability are treated by the employment of Monte-Carlo simulations. Inputs are given as probability functions instead of point estimates. Figure 3 illustrates how uncertainties are propagated through the model.

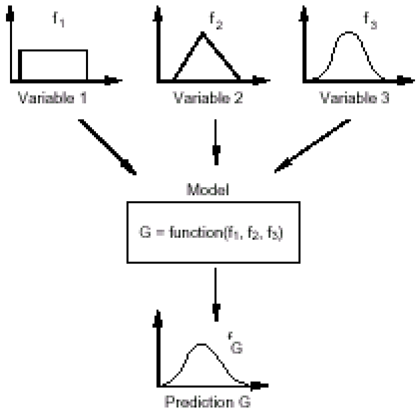

Figure 3. Propagation of uncertainty through a model[9].

The model for fire development will both consider inherent model uncertainty and the uncertainty and variability associated with the inputs. The included sub models are the state-of-the-art models for fire engineering calculations. Most of the expressions are found in the BSI´s guideline[10] on fire safety engineering principles. The BSI does also give confidence intervals for the expressions by assigning them statistical distributions.

UP-TO-DATE RESULTS

The model described above has been applied on a fictive apartment. The aim of the study was to assess the efficiency of the sprinkler system and investigate the models accuracy. The apartment consists of three rooms and the model was applied to the apartment for two scenarios. In the first scenario the apartment was not equipped with a residential sprinkler system, which was the case in the second scenario. No other changes were performed in order to illustrate sprinkler efficiency. The design fire was chosen followed the "domestic fire" curve from the CBUF project[11].

The fire development model is simulated in @RISK[12]. Ten thousand iterations were performed in order to assure convergence. Figure 4 and Figure 5 illustrated the results.

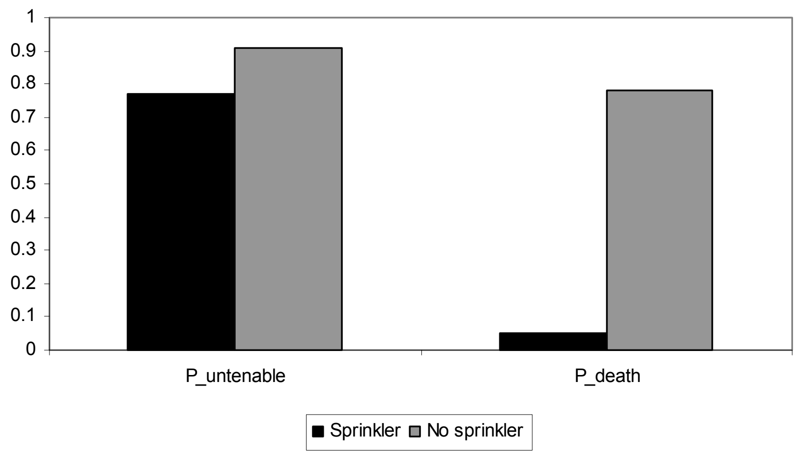

Figure 4. Probability that a given consequence occurs given fire.

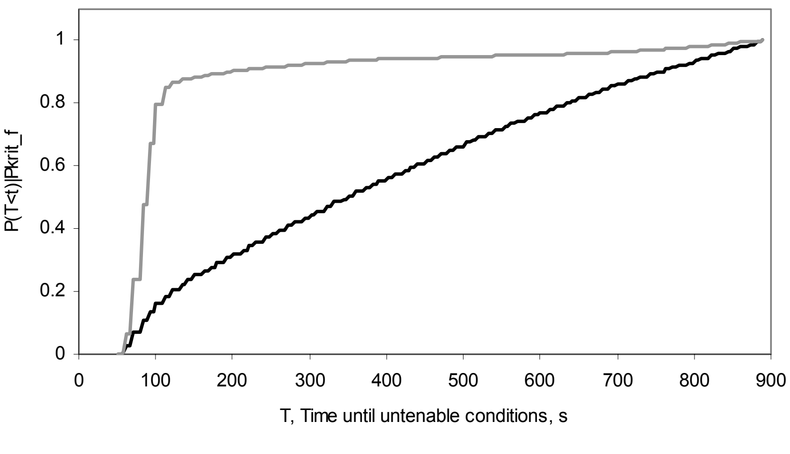

Figure 5. Probability distribution function of time until untenable conditions.

There is a great difference in the safety level between sprinkler equipped and a non-sprinkler equipped apartment. Untenable conditions could occur in an apartment with a sprinkler system, nut the time when it happens differs a lot from the non-sprinkler equipped apartment. The difference is more than 4 minutes. The analysis states that it is the heat that causes incapacitation in 4 out of 5 fires, but it is the inhalation of toxic compounds that results in death.

FUTURE RESEARCH

Future research will be undertaken where the fire development model should be linked to a human behaviour model. By doing so it is possible to analyse the safety level in residential building with or without a sprinkler system. Future research will therefore focus on human behaviour in fire and risk perception. The model will also be validated firmly. The final results from the project will be available in the beginning of 2002 as a downloadable report from the following URL: http://www.brand.lth.se/english/publications.

REFERENCES

[1] Swedish National Rescue Service Agency, *Death Fires 1999,* Report I99-077/00, Karlstad, 2000, (In Swedish).

[2] Sekizawa, A., *Statistical Analyses on Fatalities Characteristics of Residential Fires,* Fire Research Institute, Fire Defence Agency, Ministry of Home Affairs, Japan, 1988.

[3] Purser, D., *Toxicity Assessment of Combustion Products,* The SFPE Handbook of Fire Protection Engineering, 2nd edition, National Fire Protection Association, Quincy, 1995.

[4] SBF, *Death Fires 1983-1994,* Swedish Fire Protection Association, Stockholm, 1995, (In Swedish).

[5] Ruegg, R., T., Sieglinde, K., F., *A Benefit-Cost Model of Residential Fire Sprinkler Systems,* NBS Technical Note 1203, US Department of Commerce / National Bureau of Standards, Gaithersburg, 1984.

[6] Ford, J., *Automatic Sprinklers – A 10 Year Study,* Rural/Metro Fire Department, Scottsdale, Arizona, 1997.

[7] Gomberg A., Buchbinder, B., Offensend, F.J., *Evaluating Alternative Strategies for Reducing Residential Fire Loss,* NBSIR 82-2551, US Dept of Commerce, Washington, 1982.

[8] Karlsson, B, Quintiere, J.G., *Enclosure Fire Dynamics,* CRC Press, 2000.

[9] Frantzich, H. *Uncertainty and Risk Analysis in Fire Safety Engineering*, Report 1016, Department of Fire Safety Engineering, Lund University, Lund, 1998.

[10] BSI Draft for Development DD240: *Fire safety engineering in buildings. Part 1: Guide to the application of fire engineering principles*. British Standards Institution, London, 1997.

[11] Höglander K., Sundström B., *Design Fires for Preflashover Fires*, SP Report 1997:36, Swedish National Testing and Research Institute, Borås, 1997.

[12] @RISK, Risk Analysis for Spreadsheets, Palisade Corp, USA, 2000.