Available online at www.sciencedirect.com

ScienceDirect

Building and Environment 42 (2007) 1283–1290

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Probabilistic risk assessment for evacuees in building fires

G.Q. Chu[a], T. Chen[b], Z.H. Sun[b], J.H. Sun[a,*]

[a]State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, Anhui 230026, China
[b]Center for Public Safety Research, Tsinghua University, Beijing, China

Received 11 July 2005; received in revised form 10 November 2005; accepted 1 December 2005

Abstract

A probabilistic risk assessment method for evacuees in building fires is presented with consideration of some deterministic and stochastic factors. The time-dependent event tree technique is used to analyze probable fire scenarios based on operational reliability of fire protection systems. For a fire scenario, the time to untenable conditions is characterized by probability distribution with consideration of some uncertainties of design fire. Moreover, occupant pre-movement time, one of the most important proportions of evacuation time, is characterized by normal distribution to express its uncertainty. Based on calculated results of ASET and RSET for every fire scenarios, the expected number of casualties is obtained when untenable conditions occur. Moreover, according to some fire statistical data, expected risk to life (ERL) is calculated to express the risk severity. Finally, a case study for a supermarket building is presented to express the risk assessment method in detail.

Keywords: Building fire; Risk assessment; Event tree; Evacuation; Expected risk to life

1. Introduction

In recent years, urban population, the city zone area and urbanization level increase very quickly in China. Many large-scale buildings, super high-rise buildings and underground buildings come forth. In general there are some new characteristics of urban building: Transforming from traditional low rise building to high-rise or super high-rise building; Transforming from traditional single material such as brick and tile to new-style material such as steel; Transforming from simple building to large-scale modern building; Transforming from simple function building to multi-function building [1]. Due to large number of people and complex building environment, once fire occurs, the evacuation is difficult to be accomplished which may induce many people casualty. Therefore, reasonable fire safety design is very important to ensure life safety. In China, during the past years, fire safety design must comply with prescriptive codes, such as National Standards for Fire-Safety Design of Buildings (GBJ16-87) [2,3], the standard for fire safety design of buildings in the People's Republic of China. However, GBJ16-87 is a prescriptive code which is not suitable to the fire safety design of those new-style, complex and special buildings. Thus, performance-based fire protection design is employed for fire safety design in such special buildings. China has carried out some work on performance-based fire protection design and developed it for fire safety design practice. In general, fire risk assessment is the foundation of performance-based fire protection design, and appropriate performance-based fire protection design cannot be well implemented without reasonable fire risk assessment.

When building fire occurs, life safety should be ensured firstly. Therefore, risk assessment for evacuees is essential to fire safety design. With the development of performance-based fire protection design, risk-based assessment methodology for building fires has been accepted in dealing with fire safety. Robert et al. [4] concerns a performance-based fire safety analysis and design of a high-rise building with consideration of some uncertainties. Kristiansson [5] deals with the assessment for people's safety in building fire based on probabilistic methods. Frantzich [6] presents

*Corresponding author. Tel.: +86 551 3606425; fax: +86 551 3601669.
E-mail addresses: chugq@mail.ustc.edu.cn (G.Q. Chu), sunjh@ustc.edu.cn (J.H. Sun).

0360-1323/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2005.12.002

quantitative risk analysis (QRA) to quantify the risk of occupants. Yaping He [7,8] presents a probabilistic fire safety engineering assessment framework based on stochastic modeling. However, fire is a complex process which has two main characteristics: the deterministic and the stochastic rules. Furthermore, occupant evacuation process is also a complex process. Then, in order to obtain more reasonable risk assessment result, more uncertain and stochastic factors should be considered in fire risk assessment.

Risk can be defined as the product of the frequency of event and the expected consequences [9]. Risk assessment is accordingly divided into two main parts: determination of the frequency of initiating event and determination of the consequences of initiating event occurring [10]. Hall and Sekizawa [11] outlined the general framework for fire risk assessment shown as Eq. (1).

$$\text{Risk} = \int_{-\infty}^{+\infty} g(s')P(s = s')\,\mathrm{d}s'. \quad (1)$$

The term $g(s')$ in Eq. (1) is a function that transforms the severity measure s' into the measure of interest for fire risk assessment. For example, let s' be defined as the number of deaths and the measure of interest is deaths, then $g(s') = s'$. $P(s = s')$ is the probability that the severity measure s' will occur. In general, risk measure is usually based on a finite set of fire scenarios, Eq. (1) can be transformed into Eq. (2).

$$\text{Risk} = \sum_{i=1}^{n} g(s_i)P(s = s_i)\,. \quad (2)$$

In Eq. (2), n is the number of fire scenarios. For risk assessment to life, $P(s = s_i)$ is the function that denotes the occurrence probability of fire scenario i, $g(s_i)$ is the function that denotes expected number of casualties in fire scenario i.

In this paper, a probabilistic fire risk assessment method for evacuees is presented with consideration of some stochastic characteristics of fire dynamics and occupant evacuation. The framework of risk assessment for evacuees is based on Eq. (2). Therefore, the objective of risk assessment for evacuees is to determine the probability of fire scenario and the expected number of casualties in the corresponding fire scenario.

2. Fire scenarios analysis based on event tree

There are a lot of factors such as fuel characteristics and building environment which dominate fire spread and smoke movement. For a given building, the operational reliability of fire protection system is an important influential factor. In some fire risk analysis it is simply assumed that a system will function successfully. However, such is not the case in reality. In order to achieve more reasonable results, operational reliability of fire protection system should be considered in risk assessment process. The operational reliability of fire protection system will influence probable fire scenarios. For instance, fire alarm can be started either automatically by means of a signal from the sprinkler or from the smoke detectors or manually by pressing a button. It is assumed that, if the sprinkler or the smoke detector functions properly, the fire alarm will be set off automatically. If neither the sprinkler nor the smoke detector sets off the alarm, it may be started manually. In order to consider the effect of operational reliability of fire protection system on smoke movement, event tree technique is used to analyze potential fire scenarios. As far as most fire disasters are concerned, smoke causes the maximum proportion of casualties compared to heat and combustion. Statistically, more than 85% of fatalities in fire are attributed to smoke, by which, most of them transfer from narcosis to death due to the inhalation of smoke dust and poisonous species of smoke [12]. Since emphasis of this paper is to assess the risk to life in a building fire, fire protection equipment and other influencing factors that influence smoke spread will be considered in event tree analysis. Some main features are identified as part of event tree:

- Sprinkler;
- Automatic detection;
- Manual detection;
- Mechanical smoke exhaust fan.

The event tree structure used in this study is shown in Fig. 1. In this event tree a symbol "Yes" or "No" is attached to indicate the status of the corresponding event. Fig. 1 shows that there may be 10 scenarios after fire occurs. The failure probability of an event is an indispensable parameter for calculating the occurrence

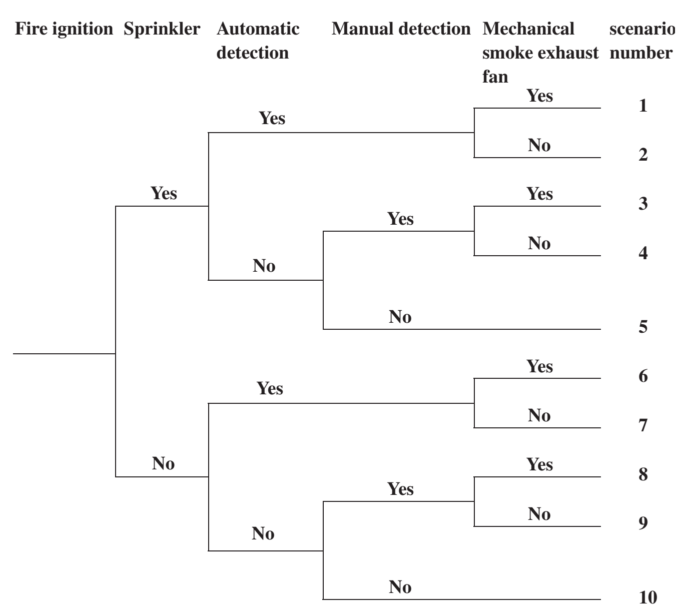

Fig. 1. Event tree and probable fire scenarios.