TECHNICAL
REPORT

**ISO/TR
16732-2**

First edition
2012-09-15

Fire Safety Engineering — Fire risk assessment —

Part 2:
Example of an office building

Ingénierie de la sécurité incendie — Évaluation du risque d'incendie —

Partie 2: Exemple d'un immeuble de bureaux

Reference number
ISO/TR 16732-2:2012(E)

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Published in Switzerland

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Foreword

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In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 16732-2 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO/TR 16732 consists of the following parts, under the general title *Fire safety engineering — Fire risk assessment*:

— *Part 1: General*

— *Part 2: Example of an office building* [Technical Report]

— *Part 3: Example of an industrial property* [Technical Report]

Introduction

This part of ISO/TR 16732 is an example of the application of ISO 16732-1, prepared in the format of ISO 16732-1. It includes only those sections of ISO 16732-1 that describe steps in the fire risk assessment procedure. It preserves the numbering of sections in ISO 16732-1 and so omits numbered sections for which there is no text or information for this example.

This part of ISO/TR 16732 is intended to illustrate the implementation of the steps of fire risk assessment, as defined in ISO 16732-1. Some steps are well illustrated by the example, and others are not well illustrated. The text of this part of ISO/TR 16732 indicates where the example is strongest.

Fire Safety Engineering — Fire risk assessment —

Part 2:
Example of an office building

1 Scope

This part of ISO/TR 16732 is an example of the application of ISO 16732-1, prepared in the format of ISO 16732-1. It is intended to illustrate the implementation of the steps of fire risk assessment, as defined in ISO 16732-1.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16732-1:2012, *Fire safety engineering — Fire risk assessment — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16732-1 apply.

4 Applicability of fire risk assessment

This example was conducted to support a policy analysis of alternative national courses of action for fire safety for a class of properties. This situation qualified under several of the circumstances cited in Clause 4 of ISO 16732-1:2012. A wide range of scenarios was deemed to be necessary. There were multiple fire safety goals which made it inappropriate to use a short list of scenarios to represent all scenarios. The objectives were stated in risk terms such as expected annual losses.

5 Overview of fire risk management

Clause 5 of ISO 16732-1:2012, including Figure 1, is not reproduced here; it is not part of the calculations.

6 Steps in fire risk estimation

Risk assessment is preceded by two steps: establishment of a context, including the fire safety objectives to be met, the subjects of the fire risk assessment to be performed and related facts or assumptions; and identification of the various hazards to be assessed.

6.1 Overview of fire risk estimation

Figure 1 describes the sequence of steps involved in fire risk estimation.

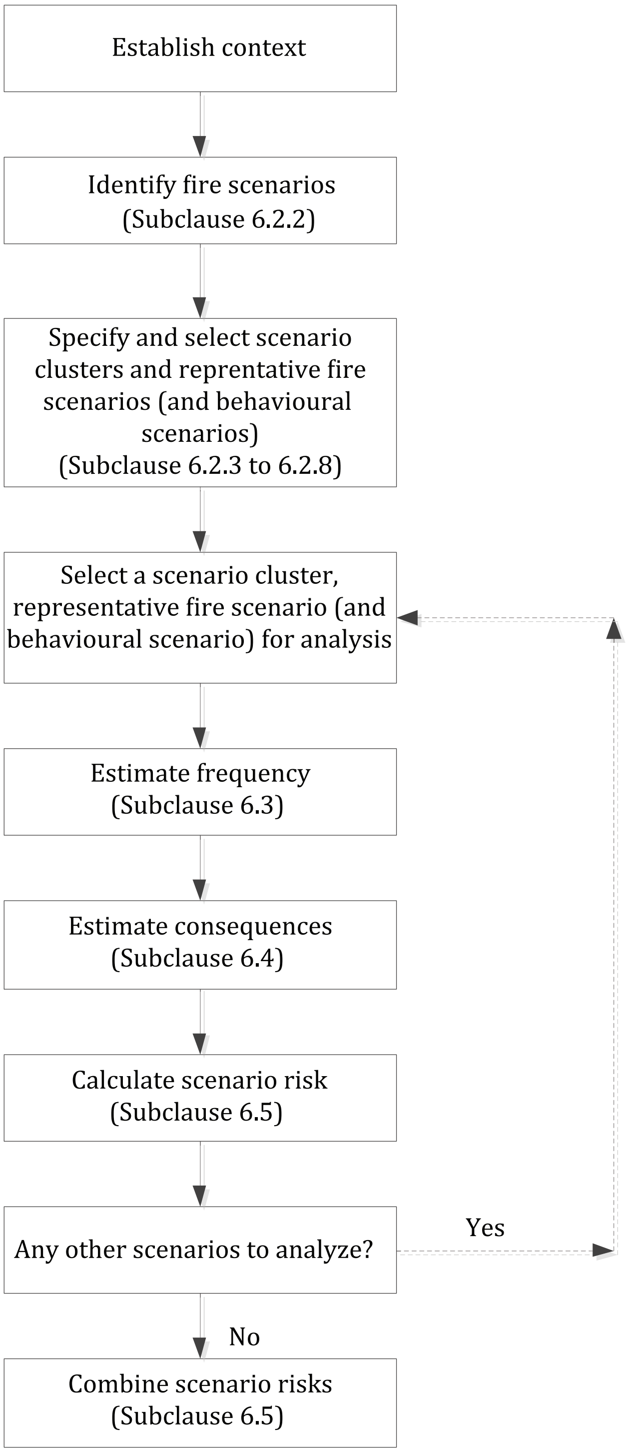


Figure 1 — Fire Risk Estimation Flow Chart

Fire risk estimation begins with the establishment of a context. The context provides a number of quantitative assumptions, which are required with the objectives and the design specifications to perform the estimation calculations.

6.1.1 Objectives

The main objectives and requirements of the building owner are to

a) provide the occupants with a level of fire safety that meets the building code requirements,

b) provide a safe area for occupants with disabilities,

c) minimize the potential for fire and smoke damage so as to minimize business losses to tenants, and

d) minimize the cost of fire protection and expected fire losses.

In the case study[1], the objectives were defined as (a) equivalent life-safety performance to that provided by a reference, code-compliant design, and (b) equivalent or better net cost over monetary benefits as compared to the reference design (i.e. cost effective design for property protection). Equivalence is to be established through engineering analysis using a fire risk estimation modelling package developed by the analysts for use on cases like this one.

6.1.2 Design Specifications

Several alternative designs were considered, differing in the use or non-use of automatic sprinkler protection, the use of different fire resistance ratings, and the use or non-use of a refuge area in addition to sprinklers.

a) Option 1, the reference option, is the code-compliant option: with a fire resistance rating (FRR) of 2 h, sprinkler protection (with an assumed 95 % reliability), without a refuge area, and with a central alarm with voice communication, as described in the NBCC requirements[2].

b) Option 2 is the same as Option 1 but with a slightly lower FRR of 90 min. This option is used to check the reduction in protection cost and the corresponding increase in risk.

c) Option 3 is the same as Option 2 but with a refuge area to help reduce risk. There was no consideration of an option with a refuge area but with no sprinklers; this analysis is not intended to comment on the attractiveness such an option would have had if it had been considered.

d) Option 4 is the same as Option 2 but with a 99 % reliability of the sprinkler system to help reduce risk.

e) Option 5 is the same as Option 2 but without sprinkler protection to check the risk without sprinklers.

Table 1 — Fire protection design options considered[1]

Design Option	Fire Resistance Rating	Refuge Area	Sprinklers
	(min)		(% Reliability)
1 (Reference)	120	No	95
2	90	No	95
3	90	Yes	95
4	90	No	99
5	90	No	No

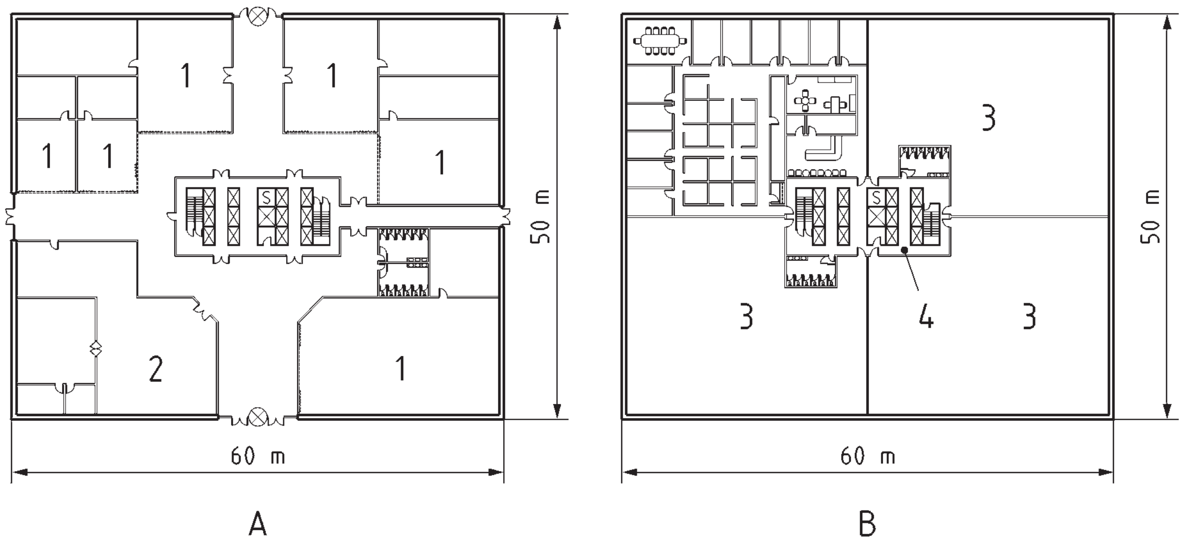
The building is a 40-storey, steel-framed, office building 60 m long by 50 m wide, with no basement. The layout of the floors is shown in Figure 2. The centre core contains the elevator, stair and service shafts, which provides

a) a profitable use of the perimeter and window area of the building for office space,

b) a simple floor layout that can be easily compartmented and fire separated, and

c) a refuge area that may act as a temporary safe place for occupants with disabilities and those who cannot evacuate during an emergency.

The ground floor has a restaurant, various retail stores, a lobby area at the main entrance, and three side exits with one connected directly to the stairs via a protected corridor. Floors 2 to 40 are divided into four spaces, suitable for use by professional companies (e.g. law offices). Each space can have two means of egress to the centre core area.



Key

1 Store
2 Restaurant
3 Office space
4 Refuge area
A Ground floor
B Floors 2 to 40

Figure 2 — Floor plans[1]

Since the building is an office building, the occupants are mainly office workers with the exception of some working in the restaurant and in the retail stores. The occupants on the upper floors with impaired mobility are assumed, in case of a fire emergency, to be helped by coworkers or to wait in the refuge area for rescue by the firefighters when they arrive on scene. The number of occupants per floor is assumed to be 300 (one occupant per 9.3 m^2 usable space, as per NBCC[2]). The refuge area in Figure 2 can accommodate 300 people. The total number of occupants in the building is 12,000. For design options without a refuge area, the layout is the same, but the indicated refuge area is not so extensively protected by fire-rated walls and smoke control systems.

6.2 Use of scenarios in fire risk assessment

6.2.1 Overview of specification and selection of scenarios

This step is just an introduction and does not need to be implemented as a step. The following steps define how the scenarios are selected in this study.

This step could also require a sensitivity analysis to determine the hazards that have the most impact on the probability of failure. This was not done for this example as the statistics used to define the probability of fire start were based on typical fire hazards in office buildings.

6.2.2 Combining scenarios into scenario clusters

This example began with a concise, parametric description of the universe of possible scenarios.

The scenario structure defines three distinct types of fires:

a) smouldering fires, where only smoke is generated;

b) non-flashover flaming fires, where a small amount of heat and smoke is generated; and

c) flashover fires, where significant amounts of heat and smoke are generated with a potential for fire spread to other parts of the building.

At this level of detail, the scenario specifications are not sensitive to detailed differences in the burning properties of initial fuel packages, let alone to the ease of ignition or burning properties of common major secondary fuels, such as large pieces of furniture or room furnishings, including floor, wall or ceiling coverings.

The definition of the type of fire is based on the severity of the fire when it was observed and recorded by the firefighters upon their arrival at the scene of the fire. Of course small fires can develop into fully developed fires (another name for flashover fires) if they are given enough time and the right conditions. However, the fire conditions at the time of fire department arrival are the ones used. They represent the fire conditions that the occupants are exposed to prior to fire department extinguishment and rescue operations.

The three fire types are extended into six scenario clusters by adding consideration of the status (open or closed) of the door to the room of fire origin. When the door is open, this may reflect the absence or failure of self-closing devices or human-caused obstructions that block the door open.

The modelling package used in the example includes a set of standard design fires. The initiating conditions of the fire and the status of the door from the first involved compartment are taken from the scenario cluster specifications. Other parameters are taken from the description of the subject property, which in this example was a 40-storey office building with specified room sizes and other dimensions, as well as standard fuel loads in the rooms and occupant loads and locations in the building. Some of these standard assumptions for an office building are taken from values set in the national building code. For some parameters – such as the location of the ignition point – the case study documentation does not clearly indicate how the parameters were determined. Details on such parameters can be found in the fire growth model.

The representative fire scenarios for the scenario clusters are therefore taken from the library of available design fires based on the best match to the defined characteristics of the subject property.

6.2.3 Exclusion of scenarios with negligible risk

In this example, the use of fire statistics to identify fire scenarios and to assemble the scenarios into scenario clusters made it unnecessary to exclude any scenarios based on negligible risk.

6.2.4 Demonstrating that the scenario structure is appropriate and sufficient

In the example, the scenario structure was comprehensive by definition, in that all types of fires were included in the scenario clusters. Questions could still remain regarding the representativeness of representative scenarios chosen for each scenario cluster, with respect to any conditions not defined by the subject property’s specifications, the scenario cluster specifications, or the national building code’s standard assumptions for engineering analysis. The location of the ignition point is an example of a condition not defined by any of those sources. The case study did not perform any analysis to demonstrate representativeness of its choices for those conditions.

Many other scenario characteristics, including the timeline of fire growth and spread of fire products, are derived from the modelling package operating on the externally defined initiating conditions. Therefore, the representativeness of those characteristics of the scenarios would depend in large part on the evidence for the validity of the models. That is discussed later.

This approach is not well designed to capture extreme events such as the fire that led to the collapse of the World Trade Center towers in New York City in 2001. This type of scenario should be treated separately from the more typical scenarios considered here. For analysis of alternative policies for a class of buildings, the analysis of extreme events can be conducted in a side analysis, but no such analysis was conducted in this example.

6.2.5 Fire risk assessment without explicit scenario structures

Subclause 6.2.5 of ISO 16732-1:2012 is not relevant in this example.

6.2.6 Behavioural scenarios

As noted above, this example used only one behavioural scenario, in which the initial conditions (e.g. number and location of occupants) were derived from assumptions tailored to the subject property or from standard assumptions in the national building code. However, the data used for the occupants' speed of movement and their response time for this behavioural scenario is derived from experiments and would provide a conservative estimate of evacuation times. Using additional behavioural scenarios would not affect the results of this case study very much. Other behavioural scenario conditions were derived from the modelling package operating on those initial conditions.

It should be mentioned that the models relating to occupant response and evacuation use four categories of occupants: senior and children, occupants with special needs, able-body female occupants, and able-body male occupants. A travel speed is assigned for each category. The locations of the occupants and the types of warnings (cues) they receive are also taken into consideration.

6.2.7 Fire risk assessment for selecting design fire scenarios for deterministic analysis

Subclause 6.2.7 of ISO 16732-1:2012 is not relevant in this example.

6.3 Characterization of probability

The probability of occurrence of each of the three types of fire is based on statistical data gathered by fire departments in Canadian provinces and territories. In Canada, statistics[3] show that the probability of fire starts in office buildings is 7.68×10^{-6} per m^2. Of these fires, 24 % reach flashover and become fully-developed fires, 54 % are flaming fires that do not reach flashover and the remaining 22 % are smouldering fires that do not reach the flaming stage.

There is a procedure in the modelling package that permits the probability of fire start to be modified when it is judged that the building under consideration is different from a typical building in terms of fuel load or combustibles, and heat sources[4]. The probabilities for some other parameters is obtained from engineering judgment (e.g. probability of the door to the compartment of fire origin being open). Still other probabilities, such as probability of fire spread, probability of fire department notification and intervention, probability of fire fighting effectiveness, and probability of rescue effectiveness, are derived from a combination of available relevant statistics, engineering judgment, and prediction by the modelling package. For example, the probabilities of glass breakage and barrier failure (see Figure 3) are determined in an entirely deterministic manner from the model's prediction of developing fire size and effects.

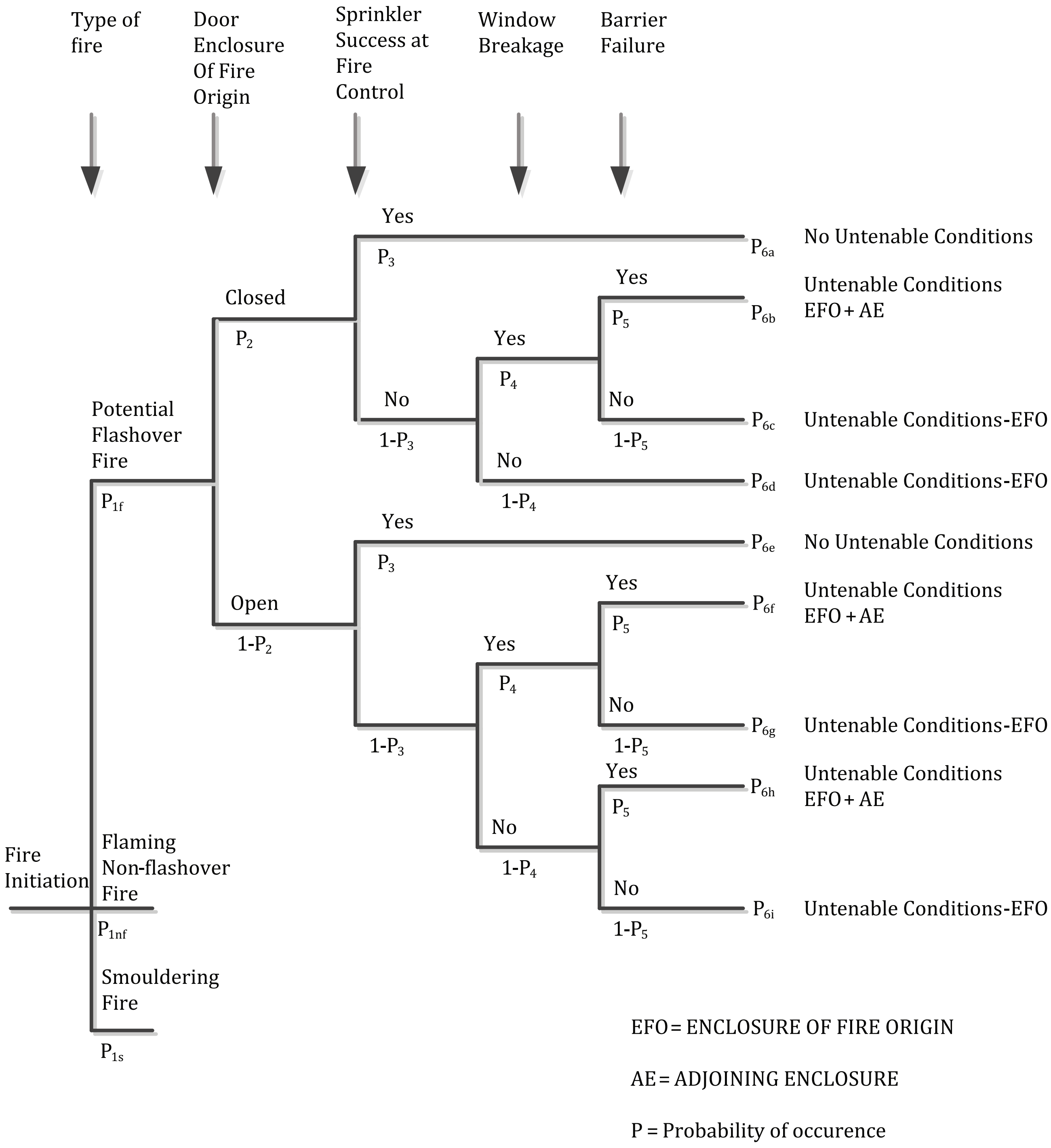


Figure 3 — Typical fire scenario structure based on an event tree formulation

Engineering judgment can be made more systematic and consistent from one engineer to another through the use of Delphi methods or other explicit procedures for reducing bias and improving the quality of estimates. [For a description of the Delphi method, see, for example, N. Dalkey and O. Helmer, “An experimental application of the Delphi method to the use of experts,” Management Science, Vol. 9 (1963), pp. 458-467. For a comparison of the Delphi method to other procedures, see, for example, F. Woudenberg, “An evaluation of Delphi,” Technological Forecasting and Social Change, Vol. 40 (1991), pp. 131-150].

Engineering judgment can be done for point values or for ranges. The latter will be subject to less disagreement between estimators and will be sufficient for use in a risk matrix or other qualitative fire risk assessment procedure. [For guidance on elicitation of engineering judgment-based estimates, see, for example, A. Kidd, ed., Knowledge Elicitation for Expert Systems: A Practical Handbook, Plenum Press, New York, 1987].

As an aid to probability estimation by engineering judgment in cases where relevant data are nearly or completely non-existent, a risk matrix may be used in which all probability estimates are channeled into a small number of well-distributed values. For example, a five-value protocol with values separated by an order of magnitude would use 0.5 %, 5 %, 50 %, 95 %, and 99.5 % as values. A five-value protocol with values separated by half an order of magnitude would use 5 %, 16 %, 50 %, 84 %, 95 %.

The engineering judgments used in this example were developed less formally and without the benefit of these methods.

6.4 Characterization of consequence

There are a number of ways to characterize consequences. Each way has advantages and disadvantages. In the present example, the consequences were quantified using deterministic models.

6.4.1 Consequence estimation from loss experience

Subclause 6.4.1 of ISO 16732-1:2012 is not relevant in this example.

6.4.2 Consequence estimation from models

6.4.2.1 Fire growth

In the example, the fire growth model is a zone model using a single zone for a compartment. It predicts the development of the six design fires, mentioned above, in the compartment of fire origin using representative fuels, such as polyurethane slabs for residential furniture and wood cribs for office furniture[5]. The model calculates the burning rate, room temperature and the production and concentration of toxic gases as a function of time. With these calculations, the model determines the time of occurrence of five important events:

a) time of fire cue (that can be detected by human senses);

b) time of smoke detector activation;

c) time of heat detector or sprinkler activation;

d) time of flashover; and

e) time of fire burnout.

The model also calculates the mass flow rate, the temperature and the concentrations of CO and CO_2 in the hot gases leaving the fire compartment.

6.4.2.2 Smoke movement beyond the initial compartment

Based on the building characteristics and internal air movement due to temperature differences between the inside and outside of a building, smoke movement in the building is calculated as a function of time. The smoke movement model[6] also calculates the critical time in the stairwells. This time is defined as the time that the build-up of smoke at a level that the occupants cannot use the stairwells to egress. The trapped occupants are then exposed to the build-up of smoke and toxic gases in the building until the fire department arrives at the fire scene to rescue them. Life hazards to the occupants are assessed by the total dose of toxic gases that the occupants have inhaled into their body up to the time of the fire department's arrival.

6.4.2.3 Occupant response and evacuation

Depending on where the occupants are located, they receive the various warning signals at different times. As a result, occupants at different locations would respond at different times. The occupants are assumed to respond when a fire could be detected by fire cues (state 1), smoke or heat detectors (states 2 and 3). The response of occupants in an emergency situation follows a process called perception, interpretation and action (PIA) [7]. The clearer the signals are that there is an impending danger, the more likely and more quickly the occupants would go through the PIA process and respond.

The fire signals can be from any of the following:

a) fire cues detectable by human sensors;

b) warnings from other occupants;

c) warnings from firefighters;

d) alarm from local detectors;

e) central alarm; and

f) central alarm with voice communication.

The probability of interpreting the above signals as fire signals depends on what the signal is; i.e. higher probability for direct perception of a fire and lower in the case of a central alarm bell. The probability of taking action to evacuate depends on the interpretation of the fire signals; i.e. higher probability for a more definite interpretation and lower for a less definite interpretation that there is impending danger. In addition, the model assumes that the probability of receiving alarms from local detectors or central alarms depends on the reliability of detectors and alarms. The probability could be close to 1 when the detectors and alarms are properly installed and maintained, or close to 0 otherwise.

Once an occupant has decided to respond, the evacuation can be calculated by following the movement of the occupant from the original location, through corridors, stairwells and eventually out of the building. The occupants would be trapped on their floors if the stairwells become untenable because of the build-up of smoke. This method allows the user to calculate whether the occupants can successfully evacuate a building.

6.4.2.4 Deaths as a consequence

Based on outputs from the smoke movement and occupant response and evacuation models, life hazards to the occupants are assessed by the total dose of toxic gases that the occupants have inhaled into their body up to the time of the fire department's arrival[8]. The occupants would be trapped on their floors if the stairwells become untenable because of the build-up of smoke. When this happened, the trapped occupants are then exposed to the build-up of smoke and toxic gases in the building until the fire department arrives at the fire scene to rescue them, otherwise they would be considered dead.

6.4.2.5 Property damage as a consequence

Based on outputs from the smoke movement model and fire spread model, the costs of heat, smoke, and water damage for a building structure and its contents are estimated, for the fire scenario being considered. The damage estimates are based on statistical averages of monetary damages for recent fires in the same kind of property.

6.4.3 Consequence estimation from engineering judgment

Subclause 6.4.3 of ISO 16732-1:2012 is not relevant in this example.

6.5 Calculation of scenario fire risk and combined fire risk

In the example, scenario fire risk is calculated as probability times consequence for each of two measures of consequence, life loss and property damage. Combined fire risk is then calculated as the sum of scenario fire risk for life loss and for property damage. The former is used as a decision-making parameters called expected risk to life (ERL).The latter is combined with cost for the design relative to cost for the reference code-compliant design to produce a second decision-making parameter called fire cost expectation (FCE).

ERL is the expected number of deaths per year as a result of fire in the subject building. FCE is the expected total fire cost, which includes the capital cost for passive and active fire protection systems, the maintenance and inspection costs for the active fire protection systems, and the expected losses resulting from fire in subject building.

The separation of life risks and protection costs eliminates the difficulty of assigning a monetary value to human life and allows for a separate comparison of risks and costs. The ERL value can be used to determine whether a fire safety design meets the performance code requirements, or whether it provides a level of safety that is equivalent to that of a code-compliant design in a prescriptive code, whereas the FCE value can be used to identify cost-effective designs.

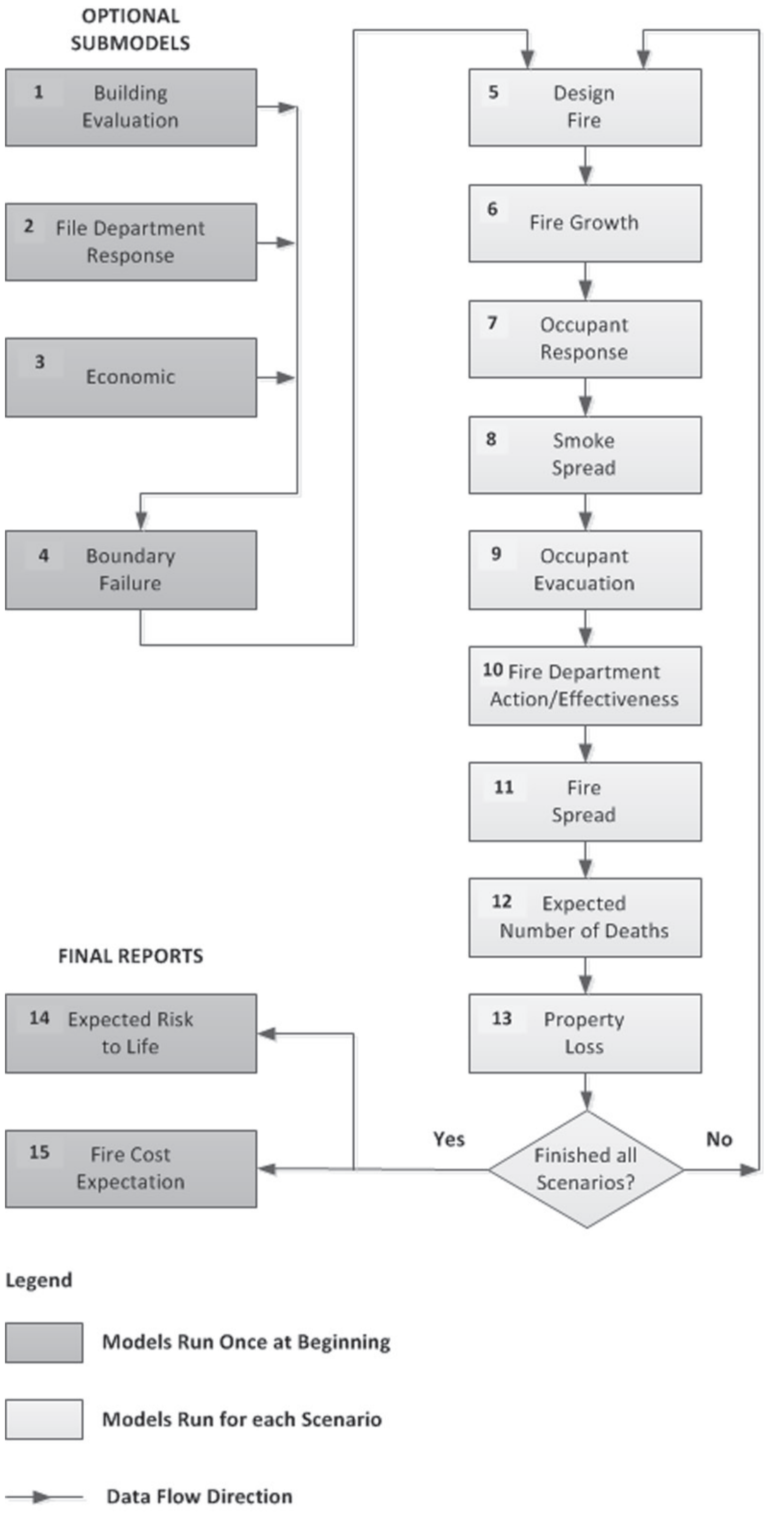


Figure 4 — Modelling package flowchart[9]

Figure 4 provides an overview of the models included in the modelling package. The package includes two optional sub-models (Building and Risk Evaluation and Fire Department Response) that can be run if the building fire characteristics and fire department response are not considered typical. The Boundary Element Failure and Economic sub-models are run only once to obtain the failure probability values of boundary elements and the capital and maintenance costs of fire protection systems. The other 10 sub-models are run repeatedly in a loop to obtain the expected risk to life values and the expected fire losses from all probable fire scenarios.

7 Uncertainty, sensitivity, precision, and bias

The example did not include a formal analysis of uncertainty or sensitivity.

The models employed use conservative engineering assumptions, which can result in over-prediction of life loss and property loss. This is not so much a problem for risk measure that is estimated risk to life relative to the code-compliant reference design, because the biases work the same way on both calculations. For fire cost expectation, however, the potentially conservative over-prediction of property damage will not be offset by comparable over-prediction of the costs of a design. Therefore, some cost-effective designs can appear less cost-effective or even not cost-effective.

8 Fire risk evaluation

8.1 Individual and societal risk

This example dealt exclusively with societal risk in that it was focused on the implications of alternative policies for risk in an entire class of buildings.

8.2 Risk acceptance criteria

In this example, the risk acceptance criteria were derived based on calculation of the risk associated with the baseline. The baseline or reference case was the building code compliant case, and the other cases were measured against this reference.

8.2.1 Baseline from defined recent experience

Subclause 8.2.1 of ISO 16732-1:2012 is not relevant in this example.

8.2.2 Establishing criteria based on baseline

8.2.2.1 Building code prescriptive requirements[1)]

Because fire risk evaluation is conducted through comparison for equivalency between estimated risk and cost for an alternative design and estimated risk and cost for a reference code-compliant design, it is appropriate to summarize the building features required for code compliance.

The prescriptive requirements of the national building code used are still part of this code, and alternative design solutions and equivalency are permitted provided that any alternative design can be demonstrated to provide the same safety level as implied by the prescriptive requirements. This existing legal framework coincides with the fire risk assessment approach used here, in which the baseline was defined by the prescriptive requirements and the implied risk provided the criteria for acceptable risk. For the 40-storey building being considered in this case study, the relevant prescriptive requirements are as follows:

a) **Fire Separation**: The building is required to be of non-combustible construction with major structural elements having a fire resistance rating (FRR) of not less than 2 h. On each floor, the FRR of partition compartment walls can range from 15 min (between office suites) to 2 h (from restaurant to retail store). Every door in a fire separation is required to be fire-rated and equipped with a self-closing device, designed to return the door to the closed position after each use.

b) **Exits**: Two exit stairs are required, and must be located so that the travel distance to at least one is not more than 40 m. This requirement is met in the layout of this building.

c) **Detectors and Alarms**: The building is required to have a fire alarm system and a voice communication system. Manual pull stations are required near principal entrances and exits. Smoke detectors are required in stairshafts. Fire detectors are required in storage areas and elevator shafts.

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1) The National Building Code of Canada was used in this study.

d) **Automatic Sprinklers**: Sprinkler protection is required for this building.

e) **Stairwell Pressurization**: Pressurization is required for stairwells serving anything below ground level. Stairwells serving above ground level are naturally vented and they are not required to be pressurized.

f) **Limiting Distance**: The building is located at a distance to the property line that satisfies the requirements of the NBCC in order to minimize the potential for fire spread to adjacent buildings.

8.2.2.2 Results of Fire Risk Evaluation

The results are shown in Figure 5 and Figure 6.

In Figure 5, the ERL of each option is compared to the reference option, which has a relative ERL of 1 (normalized against itself).

In Figure 6, the FCE of each option is shown, which includes the capital costs of passive and active fire protection systems, the worth of the annual maintenance cost of the active fire protection system and the worth of annual fire losses (building restoration cost) as a result of damage the fire and smoke.

For Option 2, the results show that this option has the same relative ERL of 1.0 (the actual numerical value is at 1.04), but has a lower FCE. This is expected because a slightly lower fire resistance rating (FRR) would increase the risk slightly due to fire spread and a correspondingly lower fire protection cost (with a slight increase in fire losses).

Option 3 is shown to have a lower relative ERL of 0.5 and a lower FCE, when compared to the Reference Option. This is possible since the refuge area protects a large number of trapped occupants who may not be able to evacuate for some of the design scenarios. The FCE is lower because of the lower FRR. The active protection cost is slightly higher (not very visible in figure) because of the use of a smoke control system, but the property loss is lower because smoke control reduces smoke damage.

Option 4 is shown to have a slightly lower relative ERL of 0.9 and a lower FCE, when compared to the Reference Option. Sprinkler protection has a significant impact on flashover fires, limited impact on non-flashover fires and no impact on smouldering fires. The reduction in risk is mainly due to the reduction in the probability of flashover fires.

Option 5 is the one without sprinkler protection. As expected, both the relative ERL and the fire losses increase significantly, although the active protection cost is reduced.

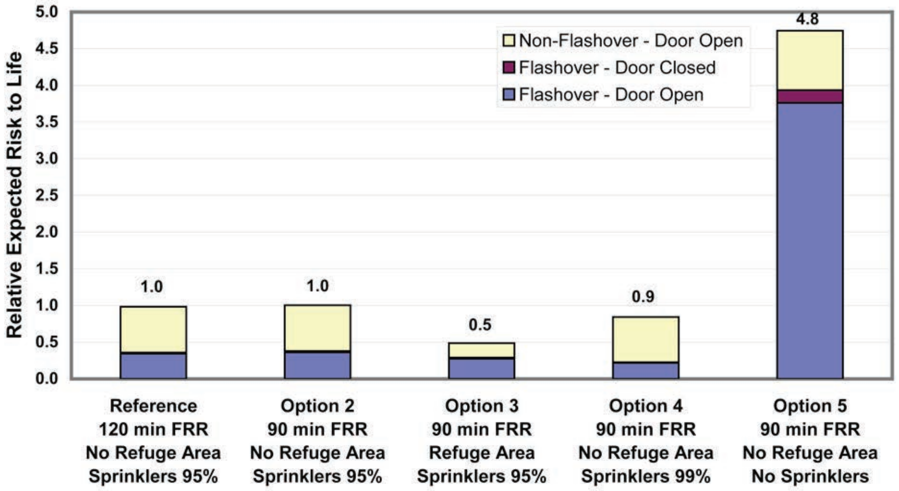

Figure 5 — Relative expected risk to life for the five design options shown in Table[1]

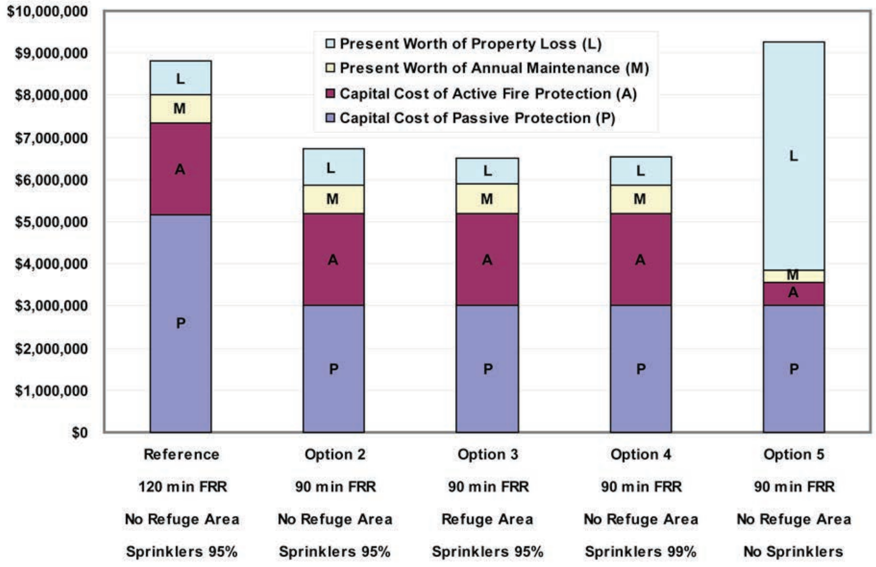

Figure 6 — Fire cost expectation for the five design options shown in Table[1]

Looking at the results of Figure 5 and Figure 6, they show two cost-effective options. The first is Option 3, which uses a refuge area where smoke control was used to protect the occupants. This option has a relative ERL of 0.5 when compared to the Reference option, and an FCE of approximately $6.5 million, which is much lower than the $8.8 million for the Reference option. The second option is Option 4, which uses a higher reliability sprinkler system, where higher maintenance is implied. This option has a relative ERL of 0.9 and an FCE of approximately $6.5 million.

Both of these options have lower expected fire losses, which should minimize business down time. Option 3 would be considered the better of the two because it provides safety for occupants with disabilities and has an overall lower ERL.

8.2.3 Acceptable frequency and revised criteria for multiple-death events

Subclause 8.2.3 of ISO 16732-1:2012 is not relevant in this example.

8.2.4 Acceptance based on ALARP

Subclause 8.2.4 of ISO 16732-1:2012 is not relevant in this example.

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ICS 13.220.01

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