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Fire safety engineering — Examples of fire safety objectives, functional requirements and safety criteria

Ingénierie de la sécurité incendie — Exemples d'objectifs de sécurité incendie, d'exigences fonctionnelles et de critères de sécurité

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ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

Introduction

The vast majority of fire safety designs rely on prescriptive specifications written into regional, national, or local regulations. Currently, various engineering approaches are also allowed by these regulations, although information needed for an engineering approach is still generally obtained from conventional test methods. Fire safety engineering (FSE) is a discipline increasingly being used throughout the world in support of performance-based design, i.e. the reliance on engineering methods to determine whether a given design meets stated performance objectives. ISO 23932 provides general principles for a performance-based methodology for engineers to assess the level of fire safety for new or existing built environments. Fire safety is evaluated through an engineered approach based on the quantification of the behaviour of fire and people and based on knowledge of the consequences of such behaviour on life safety, property and the environment.

The difference between prescriptive and performance-based approaches to fire safety design is highlighted in ISO 23932 by emphasizing the development of quantifiable fire safety design objectives and related functional requirements as the first step in a performance-based analysis. According to ISO 23932, the fire safety objectives include, for example, safety of life, conservation of property, continuity of operations, protection of the environment and preservation of heritage.

In ISO 23932, it is also mentioned that explicit performance criteria should be developed for each functional requirement. Performance criteria are engineering metrics that are expressed in deterministic or probabilistic (e.g. measures of fire risk) form to determine if each functional requirement has been satisfied by the fire safety design.

As a preliminary work prior to producing ISO standardized documents for fire safety objectives, functional requirements and safety criteria, ISO/TC 92/SC 4 decides to collect the examples of those from the existing documents that have been developed in different countries in the course of moving towards performance-based fire safety design. So far, three countries have responded to the solicitation for such documents, i.e. Japan, France and New Zealand. The development of these documents, as summarized below, was motivated by the attempts to rationalize the existing fire safety design practices based on prescriptive building by making use of fire safety engineering methods.

Japan: First developed by the Building Research Institute during the Ministry of Construction's project for developing a performance-based fire safety design method, 1981 to 1986, and subsequently improved by the committee on fire safety design in Architectural Institute of Japan, of which the report was published in 2000.

France: Developed in the collaborative research project to establish the bases to introduce fire safety engineering into fire safety design, which was conducted with the sponsorship of French ministry for construction and home office from 2005 to 2011, involving research institutes, fire brigades, practitioners, designers and owners.

New Zealand: Developed by a working group made up of external fire experts and staff from the regulatory agency. The group was set up to research and develop a suitable fire safety design framework, in the course of amending the New Zealand Building Codes corresponding to the introduction of the Building Act 2004.

Fire safety engineering — Examples of fire safety objectives, functional requirements and safety criteria

1 Scope

This document compiles examples of fire safety design objectives, functional requirements and safety criteria from Japan, France and New Zealand.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
functional requirements
statement of the means to achieve specified fire safety objectives, taking into account the features of a built environment

Note 1 to entry: Mandatory functional requirements are required by building codes or national regulations; voluntary functional requirements are expressed by other interested/affected parties.

3.2
mandatory objectives
fire safety objectives, such as life safety and protection of the environment, which are required by building codes or national regulations

3.3
performance criteria
quantitative engineering specifications, which form an agreed basis for assessing the safety of a built environment design

3.4
safety factor
multiplicative adjustment applied to calculated values to compensate for uncertainty in methods, calculations, input data and assumptions

3.5
verification
process of determining that a fire safety design complies with the fire safety requirements by examining the design in the light of safety criteria

3.6
voluntary objectives
fire safety objectives, which are requirements expressed by interested/affected parties, beyond mandatory objectives

4 Examples from France, New Zealand and Japan

Annexes A to D contain examples of fire safety objectives, functional requirements and safety criteria from France, New Zealand and Japan.

Annex A
(informative)

Example of fire safety design objectives and functional requirements in France

A.1 Introduction

Fire safety design in France for life safety and property protection is mainly prescriptive and managed by regulation. Even if there are already partial openings to fire safety engineering, since only some years ago it has become increasingly obvious that more involvement in fire safety engineering need to be made in French fire safety regulations.

In mid-2005, a collaborative research project was set up, with the sponsorship of French ministry for construction and home office, involving different partners including research institutes, fire brigades, practitioners, designers and owners. The research project, which ended by mid-2011, was divided into 18 main items, clustered in three main parts:

— Development of general principles for FSE assessment:
  — FSE methodology;
  — objectives and performance criteria;
  — fire risk assessment;
  — design fire and behavioural scenarios;
  — verification of the methodology by examples;
  — validation by reconstructions of fire incidents.
— State-of-the-art and research projects regarding:
  — statistical analysis of fuel load density;
  — characterization of burning items;
  — fire development and spread;
  — structural behaviour calculations;
  — fire containment;
  — behaviour at elevated temperature of regular glazing;
  — fire protection;
  — human behaviour.
— Communication and dissemination:
  — teaching of FSE in universities or high schools for engineers;
  — information and awareness of actors involved in FSE;
  — publication of outcomes;

— proposals for regulation improvements.

A translation of the general principles developed within the scope of this collaborative research is given in this document. The performance-based structure consists of the three following levels:

— fire safety objectives;

— functional requirements;

— performance criteria.

Fire safety objectives which are explicitly or implicitly mentioned in French regulations (for public buildings, tall buildings, work places, warehouses, industrial plants, etc.) were identified. Functional requirements were selected mainly by brain storming among the members who joined this research project.

A few examples of vulnerability criteria have been given, involving life safety objectives and requirements, and focusing on what should be "adequate tenability conditions". Performance criteria proposed were derived from some national or international research works or standards.

A.2 General

A.2.1 Purpose

This document provides examples of fire safety objectives, functional requirements and performance criteria for interested parties involved in a performance-based approach to assess the level of fire safety of a built environment. The development of quantifiable fire safety objectives is the first step in a performance-based analysis. This is an alternative to prescribed regulatory requirements, giving more freedom in the design of built environments, a better cost/benefit within sustainability development, while retaining equal or higher level of safety performance compared with the prescribed approach.

A.2.2 Scope

The examples developed in this document can apply when performing the fire safety engineering process for a whole built environment or part of it, and for new or existing buildings. They can be used when the performance-based approach is considered as an alternative to a prescriptive acceptable solution (in this case, performance criteria are not defined but relative to the performance reached by the acceptable solution when considering the selected fire safety objectives and functional requirements).

These objectives can be used as either mandatory or voluntary fire design objectives, depending on the regulatory requirements which need to be fulfilled.

It is necessary to have an agreement on any assumptions taken for objectives, functional requirements and performance criteria (when they are not explicitly given in the regulation) from authorities having jurisdiction, prior to performing the assessment work as such.

A.2.3 Terms and definitions

A.2.3.1

compartment

enclosed space, which may be subdivided, separated from adjoining spaces by fire barriers

A.2.3.2

media impact

qualitative value of exposure through a given medium

A.2.3.3

safe refuge

temporary location that is free from immediate danger from effects of fire

A.2.3.4

strategic function

capacity or resource of an entity or an organization that maintains its ability to achieve future outcomes and determines its long-term performance

A.2.3.5

sudden change

transition within a few seconds

A.2.3.6

untenable condition

condition such that people are unable to take effective action to accomplish their own escape to a place of safe refuge

A.2.4 Symbols and abbreviated terms

Shown below are the abbreviated terms that are used in this document.

FNR	functional requirement
FSE	fire safety engineering
OBJ	objective

A.3 Fire safety objectives

The fire safety objectives which need to be addressed in design of a building can be related to the safety of life, property, environment, continuity of operations, or cultural heritage. The different categories of objectives are summarized below.

OBJ 1: Health and life safety

Life safety is often the most important objective of fire safety design. It first involves occupants of the building and may extend to firefighters who are expected to assist in evacuation or prevent extensive uncontrolled spread of fire, and finally to third parties. Thus, three sub-objectives are defined.

OBJ 1-1: Health and life safety of occupants

OBJ 1-2: Health and life safety of firefighters

OBJ 1-3: Health and life safety of third parties

OBJ 2: Environment protection

Avoiding long-term consequences of the environmental impact of fires is becoming a more apparent goal. The objectives of environmental protection in case of fire may be divided into two main groups as follows:

OBJ 2-1: Ground and water

OBJ 2-2: Atmosphere

OBJ 3: Property protection

Protection of property from fire damage aims generally at limiting any damage to the contents of the building, to the building itself, or to the vicinity of the building.

In the modern world, the cost of business interruption is also of interest because it may be much higher than the cost of direct damage to the contents and the building itself. In the same way, preservation of the strategic functions may be essential, especially when involving, for example, transportation, power, and other infrastructures necessary to the functioning of a community.

Besides, some buildings with architectural, historical or cultural importance may have values which cannot be measured on a monetary scale. Their protection against the damage caused by fire is considered to be one of the basic moral duties of the society.

Finally, in many fields of industry, a good public image is essential to success in business. A fire loss may damage public image and lead to detrimental long-term consequences.

As a result, the property protection objectives may be divided into the following sub-objectives:

OBJ 3-1: Moveable properties and real estate within the premises

OBJ 3-2: Moveable properties and real estate of third parties

OBJ 3-3: Continuity of operations

OBJ 3-4: Strategic matters

OBJ 3-5: Preservation of heritage

OBJ 3-6: Media impact

A.4 Functional requirements

Functional requirements are necessary to take into account specific conditions related to the built environment to enable the link between fire safety objectives and performance criteria.

OBJ 1-1: Health and life safety of occupants

FNR 1-1-1: No sudden change in the tenability conditions before every occupant left the room of origin

In the room of fire origin, the different factors influencing fire development and spread of fire effluents shall be such that sudden changes in the exposure conditions, which can catch the occupants before they have become aware of the hazard and have left the room, should be prevented. The underlying idea is to delay the occurrence of a flashover in this room, for example, by distancing the different combustible materials present in the room, or by using safety systems such as automatic detection or sprinkler system.

FNR 1-1-2: Adequate tenability conditions in the egress route up to any occupant left

The occupants must be able to totally evacuate the building without being subject to untenable conditions.

FNR 1-1-3: Adequate tenability conditions in space within the building, outside the room of origin, where people are waiting for rescue

The occupants must be able to remain in a safe refuge, waiting to get rescued, without being subject to untenable conditions.

FNR 1-1-4: Adequate tenability conditions for the whole duration of the fire, in space within the building where people have found refuge

The occupants must be able to remain in a safe refuge for the whole duration of the fire without being subjected to untenable conditions. This is the same as the previous functional requirement, except that the possibility to get rescued is not considered. It could lead, for example, to a fire resistance rating for the walls of the refuge more important that in the previous case.

OBJ 1-2: Health and life safety of firefighters

FNR 1-2-1: Adequate tenability conditions during the necessary time for the reconnaissance of the fire area

This mainly concerns the access paths for firefighting vehicles and the egress routes to search for the origin of the fire or to identify specific risks such as storage of gas cylinders.

FNR 1-2-2: Adequate tenability conditions during the necessary time for evacuating people

The firefighters must be able to evacuate people without being subjected to untenable conditions.

FNR 1-2-3: No sudden change in the tenability conditions when fighting the fire

Sufficient time must be available for the firefighters to get out from the room, the floor or the building before conditions have become untenable. They should not be trapped by an extremely rapid fire progress or other flashover-related phenomena that may happen in a room with combustible partition walls.

OBJ 1-3: Health and life safety of third parties

FNR 1-3-1: Adequate tenability conditions within a neighbouring built environment during the whole duration of the fire

The health and life safety of third parties must be ensured during the whole duration of the fire without forcing them to leave the premises.

FNR 1-3-2: Adequate tenability conditions in the surrounding spaces, during the necessary time, as a function of the mobility conditions of the third parties (including traffic roads)

Third parties in surrounding spaces must be able to move away from the fire zone without being subjected to the effects of the fire. Surrounding spaces include sidewalks, public or private areas, and roads for which visibility conditions may be essential.

OBJ 2-1: Ground and water protection

FNR 2-1-1: Reduction of hazardous solid or liquid fire residues

When fighting and extinguishing the fire, there are often serious releases of hazardous solid or liquid fire residues to the ground or to the waste water system, which may consequently damage the ground water or nearby lakes or rivers. Necessary measures such as containment basins must be in place to limit or contain these combustion residues.

FNR 2-1-2: Control of hazardous fire effluent released

Necessary measures must be in place to contain the hazardous, polluting or toxic products released during the fire. Highly hazardous products could be, for example, placed in specifically designated areas with a particular protection and sectioned off from other areas.

OBJ 2-2: Atmosphere protection

FNR 2-2-1: Fire effluent containment

Necessary measures must be in place to contain the smoke and combustion products released during the fire, in order to limit emissions into the atmosphere.

FNR 2-2-2: Control of hazardous fire effluent released and dispersed into the atmosphere

Necessary measures must be in place to limit the hazardous, polluting or toxic products released during the fire and dispersed into the atmosphere.

OBJ 3-1: Moveable properties and real estate within the premises

FNR 3-1-1: Preservation of a specific component within the room of origin

A specific content of the building can be considered of great interest, like a safety-deposit box or a work of art, and specific protection (automatic detection, sprinkler system, etc.) should be used to prevent any degradation.

FNR 3-1-2: Fire restricted to the room of origin

Necessary measures must be in place to avoid the spread of fire outside the room of origin.

FNR 3-1-3: Damages restricted to the room of origin

Even if the fire is restricted to the room of fire origin, the effects of the fire may cause damages to adjacent rooms. It may be necessary to avoid damages outside the room of origin.

FNR 3-1-4: Damages restricted to the compartment of origin/to the floor of origin

It is the same approach as the previous requirement, except that damages are accepted to all the rooms of the compartment or floor of origin.

OBJ 3-2: Moveable properties and real estate of third parties

FNR 3-2-1: No spread of fire to neighbouring constructions

Necessary measures must be taken to avoid the spread of fire to neighbouring constructions. For example, to avoid the spread of fire between adjacent multi-storey buildings, a classical approach is to limit the use of combustible materials in facades.

FNR 3-2-2: No damages to neighbouring constructions

Necessary measures must be in place to avoid damages to neighbouring constructions. It could be by imposing distance between buildings.

OBJ 3-3: Continuity of operations

FNR 3-3-1: Preservation of a given activity

In a company, an organization, or an association, an activity of critical importance might be subjected to specific provisions in case of fire.

FNR 3-3-2: Protection of the production capability

Necessary measures must be in place to maintain the production capability intact in case of fire.

FNR 3-3-3: Preservation of a specific device (and its supplying fittings)

Within a building, a specific device can be deemed to be essential for the good functioning of the building. Necessary measures must be in place to protect the device and its supplying fittings in case of fire.

OBJ 3-4: Strategic matters

FNR 3-4-1: Preservation of the strategic functions

Necessary measures must be in place to ensure the continuity of the strategic functions in case of fire.

FNR 3-4-2: Protection of any devices involved in strategic functions

Necessary measures must be in place to protect from the effects of the fire any devices involved in strategic functions.

OBJ 3-5: Preservation of heritage

FNR 3-5: Protection from attack to any object or construction which could not be replaced

Necessary measures must be in place to protect from the effects of the fire any objects or buildings with architectural, historical or cultural importance. Any alterations which are unavoidable should be reversible, allowing the objects or building affected to be returned to its original condition. Consequently, in some cases, fire detection would be more appropriate than fire suppression.

OBJ 3-6: Media impact

FNR 3-6: Preservation of the image from any media action

This is a global rather than an individual protection, and necessary measures must be in place to minimize the visible consequences that may damage public image and lead to detrimental long-term consequences.

A.5 Performance criteria

A few examples of criteria are proposed in this clause, focusing on what should be "adequate tenability conditions". These criteria, based on both discrete values (which are sometimes associated with a discrete time period) and dose methods (which consider time-dependent exposures and thresholds), are not exhaustive.

OBJ 1-1 and 1-3: Health and life safety of occupants and third parties

FNR 1-1-2, 1-1-3, 1-1-4, 1-3-1 and 1-3-2

Criteria 1: Maximum gas temperature of 60 °C[1][2]

Criteria 2: Maximum incident heat flux of 2 kW/m^2 (for an exposure time >10 s) or 2,5 kW/m^2 (for an exposure time <10 s)[2]

Criteria 3: Maximum radiative dose of 300 kW$^{4/3}$m$^{-8/3}$s (for an exposure time <2 min)[3]

Criteria 4: Maximum fractional effective dose (FED) of 0,3[4]

Criteria 5: Minimum visibility of 10 m (as calculated in ISO 13571)[4]

OBJ 1-2: Health and life safety of firefighters

FNR 1-2-1 and 1-2-2

Criteria 6: Maximum incident heat flux of 5 kW/m^2[5]

A.6 Bibliography

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[5] Braun E., Cobb D., Cobble V.B., Krasny J.F., Peacock, R.D. Measurement of the protective value of apparel fabrics in a fire environment. *Journal of Consumer Product Flammability*. 1980, **7**, No.1, p. 15–25

Annex B
(informative)

Example of fire safety design objectives and functional requirements in New Zealand

B.1 Introduction

In New Zealand, building regulations have traditionally been prescriptive. They did not cover emerging technologies and every combination of circumstances. Thus, prescriptive regulations have provided constraints to design that are not always appropriate to the specific building being considered.

In order to free design from such constraints, increase innovation and facilitate trade, New Zealand developed a building code to be performance based. New Zealand first introduced performance-based code in 1992 with the introduction of the Building Regulations 1992. After this time, fire engineering emerged as a specialized field, requiring university-based education and training. New Zealand's first group of locally-trained fire engineers graduated from the University of Canterbury in 1995. Over the years, fire engineering has continued to develop as a recognized, specialist field within New Zealand, playing a critical role in building design.

A review of the Building Code in 2007 recommended reform to improve and streamline the Code and its supporting documents. This review highlighted that performance requirements for fire design are non-specific and insufficiently quantified.

The review found that fire engineers were using a wide diversity of guidance and methods resulting in wide variance in fire safety reports. There was no defined approval process with inconsistent views of each local authority. Assumptions in the calculation input by fire engineers were often different for similar buildings. This was leading to an inefficient consenting process, with costly delays for developers, especially in the construction of large buildings.

In 2012, there were changes made to Building Code Clause C (protection from fire) and the supporting documents. The changes were significant in nature with quantification of performance criteria in the Building Code, new Verification Method and seven Acceptable Solutions.

The new Building Code provides a clear set of performance criteria together with Verification Method to provide a systematic approach to fire engineering design within a legislative compliance document. The Verification Method standardizes fire engineering practice and provides a consistent measure of performance in fire engineering projects across New Zealand to comply with the Building Code.

The fire design scenarios and associated design parameters are set out in Verification Method C/VM2, which applies to complex buildings. Simple buildings are covered by a suite of Acceptable Solutions C/AS1 to C/AS7.

When developing the fire safety design framework, the working group's approach was as follows.

— When there was obvious analysis available to support the chosen values in the existing Compliance Documents, it would first consider those existing Compliance Documents.

— In other cases, it would investigate the approach of overseas building codes.

There was no deliberate intention to significantly change the level of safety that previously existed and implicitly contained within the previous compliance documents. This was a factor that influenced some of the performance criteria adopted.

B.2 General

B.2.1 Purpose

All building work in New Zealand must comply with the Building Code. It is a performance-based code, which means it states how a building must perform in its intended use rather than describing how the building must be designed and constructed. This document describes the fire safety objectives, functional requirements and performance criteria from the New Zealand Building Code.

B.2.2 Scope

The Building Code contains compulsory rules for all new building work. The Building Act 2004 applies to:

— building construction, alteration, demolition or removal;

— maintenance of a building's specified systems, such as lifts and fire protection installations.

It does not cover planning and resource management, occupational safety and health.

B.2.3 Terms and definitions

B.2.3.1

available safe egress time

ASET

time available for escape for an individual occupant

Note 1 to entry: This is the calculated time interval between the time of ignition of a fire and the time at which conditions become such that the occupant is estimated to be incapacitated (i.e. unable to take effective action to escape to a place of safety).

B.2.3.2

burnout

exposure to fire for a time that includes fire growth, full development, and decay in the absence of intervention or automatic suppression, beyond which the fire is no longer a threat to building elements intended to perform loadbearing or fire separation functions, or both

B.2.3.3

evacuation time

time interval between the time of warning of a fire being transmitted to the occupants and the time at which the occupants of a specified part of a building or all of the building are able to enter a place of safety

B.2.3.4

fire load

quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces

Note 1 to entry: It is expressed in joules (J).

B.2.3.5

fire load energy density

FLED

fire load (B.2.3.4) per unit floor area

Note 1 to entry: It is expressed in megajoules per square meter (MJ/m^2).

B.2.3.6

fractional effective dose

FED

fraction of the dose [of carbon monoxide (CO) or thermal effects] that would render a person of average susceptibility incapable of escape

B.2.3.7

importance level

each of the five levels of importance of buildings, as set out in Clause A.3 of the New Zealand Building Code, that can be assigned to a building

Note 1 to entry: See Reference [1].

B.2.3.8

incapacitated

state of physical inability to accomplish a specific task

B.2.3.9.1

place of safety

<general> safe place

B.2.3.9.2

place of safety

<building> place inside a building meeting the following requirements:

a) the place is constructed with fire separations that have fire resistance sufficient to withstand burnout at the point of the fire source;

b) the place is in a building that is protected by an automatic fire sprinkler system that complies with NZS 4541 or NZS 4515 as appropriate to the building's use;

c) the place is designed to accommodate the intended number of persons;

d) the place is provided with sufficient means of escape to enable the intended number of persons to escape to a safe place that is outside a building

B.2.3.10

safe place

place, outside of and in the vicinity of a single building unit, from which people may safely disperse after escaping the effects of a fire

Note 1 to entry: It may be a place such as a street, open space, public space or an adjacent building unit.

B.2.3.11

separating element

barrier that exhibits fire integrity, structural adequacy, thermal insulation, or a combination of these for a period of time under specified conditions (in a fire resistance test)

B.2.3.12

structural adequacy

time in minutes for which a prototype specimen has continued to carry its applied load within defined deflection limits, in the context of the standard test for fire resistance

B.2.3.13

visibility

maximum distance at which an object of defined size, brightness and contrast can be seen and recognized

B.2.4 Regulatory framework

The regulation and performance of buildings sit under the following three-part framework.

— The **Building Act**, which contains the provisions for regulating building work.

— The various **Building Regulations**, which contain prescribed forms, list specified systems, define "change the use" and "moderate earthquake", and set out the rate of levy and fees for determinations.

— The **Building Code**, contained in Schedule 1 of the Building Regulations 1992, which sets performance standards all new building work must meet and covers aspects such as stability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency.

Figure B.1 illustrates the legislation that forms the building control framework governed by the Building Act.

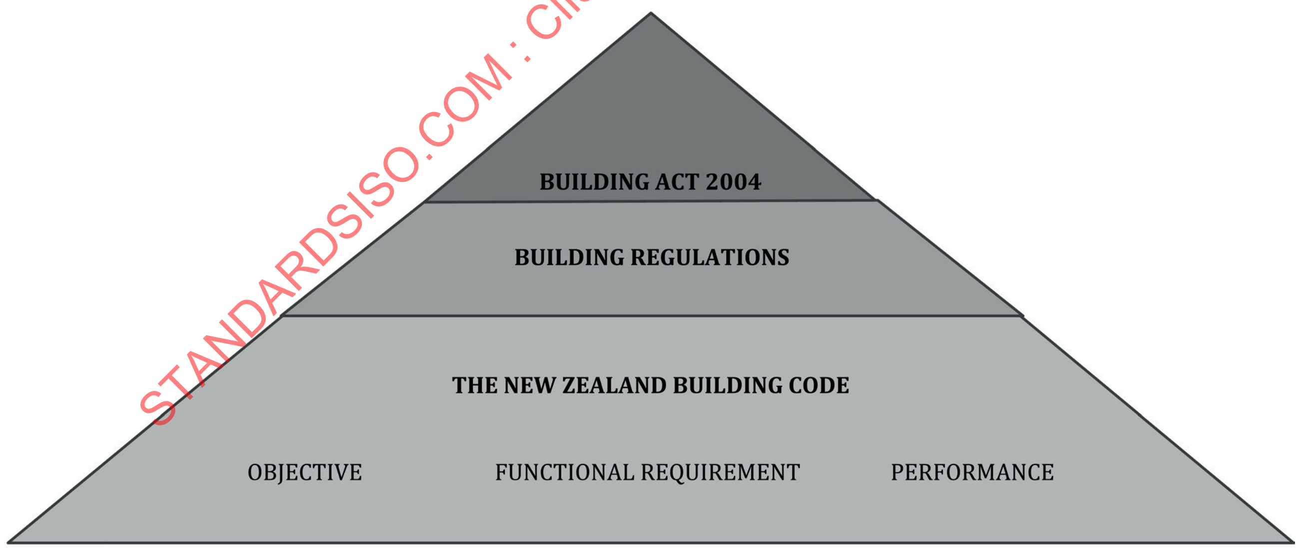

Figure B.1 — New Zealand building control framework

The Building Code sets out performance criteria that building work must meet. It covers aspects such as structural stability, fire safety, access, moisture control, durability, services and facilities, and energy efficiency. The Building Code does not prescribe how work should be done, but states how completed building work and its parts must perform.

An advantage of a performance-based Building Code is flexibility. It contains no prescriptive requirements stipulating that certain products or designs must be used. This flexibility allows developments and innovation in building design, technology and systems.

The Building Code consists of two preliminary clauses and 35 technical clauses. Each technical clause has three levels that describe the requirements for the clause and are listed below.

— Objective: Social objectives the building must achieve.

— Functional requirement: Functions the building must perform to meet the objective.

— Performance: The performance criteria the building must achieve. By meeting the performance criteria, the objective and functional requirement can be achieved.

B.2.5 Symbols and abbreviated terms

NZBC New Zealand Building Code

FSD fire safety design

FNR functional requirement

OBJ objective

PR performance requirement

B.3 Fire safety objectives, functional requirements and performance requirements

This clause describes the fire safety objectives (OBJ), functional requirements (FNR) and performance requirements (PR) that were identified from the fire safety provisions of the NZBC.

B.3.1 Fire safety objectives

B.3.1.1 Clause C1 Objectives of Clause C2 to C6 (Protection from Fire)

The objectives of Clause C2 to C6 are to

a) safeguard people from an unacceptable risk of injury or illness caused by fire,

b) protect other property from damage caused by fire, and

c) facilitate firefighting and rescue operations.

B.3.2 Functional and performance requirements

B.3.2.1 Clause C2 Prevention of Fire Occurring

C2.1 Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed, and installed in buildings in a way that reduces the likelihood of illness or injury due to fire occurring (FNR).

C2.2 The maximum surface temperature of combustible building materials close to fixed appliances using controlled combustion and other fixed equipment when operating at their design level must not exceed 90 °C (PR).

C2.3 Fixed appliances using controlled combustion and other fixed equipment must be designed, constructed and installed so that there is a low probability of explosive or hazardous conditions occurring within any spaces in or around the building that contains the appliances (PR).

Subclause C2.2 defines the maximum surface temperature that a combustible surface shall not exceed, based on long-term exposure to elevated temperatures and surface radiation from a heating appliance. The intention of declaring a specific value as opposed to a temperature rise is to reduce any dispute about the appropriate ambient temperature to assume in the application of this clause.

At first, the value of 90 °C may appear to be significantly lower than typical piloted ignition temperatures of around 200 °C. However, a review of the literature shows that wood exposed to constant heating for long periods of time may change chemically and this can result in significantly lower ignition temperatures. The recommended limiting surface temperature for long exposure times accordingly varies from 66 °C to 110 °C.

Subclause C2.3 is intended to ensure that all fixed appliances using controlled combustion and other fixed equipment are constructed and installed according to an appropriate standard. If a designer is not referring to a New Zealand Standard, it is his or her responsibility to demonstrate that the standard used is equivalent to the appropriate New Zealand Standard.

B.3.2.2 Clause C3 Fire Affecting Areas Beyond the Fire Source

C3.1 Buildings must be designed and constructed so that there is a low probability of injury or illness to persons not in close proximity to a fire source (PR).

C3.2 Buildings with a building height greater than 10 m where upper floors contain sleeping uses or other property must be designed and constructed so that there is a low probability of external vertical fire spread to upper floors in the building (PR).

Subclause C3.2 does not apply to importance level 1 buildings.

C3.3 Buildings must be designed and constructed so that there is a low probability of fire spread to other property vertically or horizontally across a relevant boundary (PR).

C3.4(a) Materials used as internal surface linings in the following areas of buildings must meet the performance criteria specified in Table B.1 (PR):

Table B.1

Area of building	Performance determined under conditions described in ISO 9705	
	Buildings not protected with an automatic fire sprinkler system	Buildings protected with an automatic fire sprinkler system
Wall/ceiling materials in sleeping areas where care or detention is provided	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in exitways	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in occupied spaces in importance level 4 buildings	Material Group Number 1-S	Material Group Number 1 or 2
Internal surfaces of ducts for HVAC systems	Material Group Number 1-S	Material Group Number 1 or 2
Ceiling materials in crowd and sleeping uses except household units and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1, 2 or 3
Wall materials in crowd and sleeping uses except household units and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1, 2 or 3

Table B.1 *(continued)*

Area of building	Performance determined under conditions described in ISO 9705	
	Buildings not protected with an automatic fire sprinkler system	**Buildings protected with an automatic fire sprinkler system**
Wall/ceiling materials in occupied spaces in all other locations in buildings, including household units	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3
External surfaces of ducts for HVAC systems	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3
Acoustic treatment and pipe insulation within air handling plenums in sleeping uses	Material Group Number 1, 2 or 3	Material Group Number 1, 2 or 3

Subclause C3.4 does not apply to detached dwellings, within household units in multi-unit dwellings, or outbuildings and ancillary buildings.

Subclause C3.4 is intended to reduce the risk of rapid flame spread on walls, floors, and ceilings, so that the fire growth rate does not significantly exceed that given in Verification Method C/VM2. The hazards of rapid flame spread on building surfaces can result in extremely rapid fire growth that can easily exceed the design fires typically used in fire engineering design and, in particular, the design fire values given in Verification Method C/VM2. While it is not possible for the Building Code to control the contents of a building, it is appropriate to place controls on the surface finishes in certain areas of a building. Controlling the surface spread of flame significantly reduces the likelihood that a fire will exceed the growth rate given in Verification Method C/VM2.

The Group Number methodology used in Subclause C3.4(a) has been the subject of significant research in Europe and Australia, and more recently in New Zealand. The current methodology applied in the Building Code of Australia was adopted as a model for the NZBC. This uses the ISO 9705 method as a reference scenario. ISO 5660-1 results have been correlated to the larger scale ISO 9705 room corner fire test and the correlation can be used for most materials. Surface linings are exposed to 100 kW for 10 min and then 300 kW for a further 10 min, and the time to reach flashover (when the heat release rate reaches 1 MW in a 3,6 m × 2,4 m × 2,4 m room) is then determined. Materials are classified from Group Number 1 (best) to Group Number 4 (worst) based on their measured time to flashover in the fire test.

Group Number 1 materials

These include non-combustible materials or those with limited combustibility. Examples are plasterboard and similar, and low-hazard materials (no flashover in 20 min). These materials meet the flashover criteria of the performance requirement of Subclause C3.4(a) for exitways.

Group Number 2 materials

These typically include many fire retardant treated timbers (no flashover in 10 min). These materials meet the flashover criteria of the performance requirement of Subclause C3.4(a) for crowd uses.

Group Number 3 materials

These typically include ordinary timber or similar products (no flashover in 2 min). These materials meet the flashover criteria of the performance requirement of Subclause C3.4(a) for all other areas.

Group Number 4 materials

These typically include exposed polyurethane foams or similar products (flashover within 2 min). Note that these materials are potentially hazardous when installed as room linings and are not acceptable in occupied spaces.

C3.4(b) Floor surface materials in the following areas of buildings must meet the performance criteria specified in Table B.2 (PR).

Table B.2

Area of building	Minimum critical radiant flux when tested to ISO 9239-1	
	Buildings not protected with an automatic fire sprinkler system	Buildings protected with an automatic fire sprinkler system
Sleeping areas and exitways in buildings where care or detention is provided	4,5 kW/m^2	2,2 kW/m^2
Exitways in all other buildings	2,2 kW/m^2	2,2 kW/m^2
Firecells accommodating more than 50 persons	2,2 kW/m^2	1,2 kW/m^2
All other occupied spaces except household units	1,2 kW/m^2	1,2 kW/m^2

Subclause C3.4(b) applies to the floor surface or the floor covering if present. A minimum critical radiant flux (CRF) is specified depending on location in the building and whether sprinklers are present. The CRF is measured in the floor radiant panel test (ISO 9239-1). For general use spaces, the level of performance required is low. This reflects previous requirements in New Zealand where controls on floor coverings in spaces other than exitways were minimal or nonexistent.

C3.4(c) Suspended flexible fabrics or membrane structures used in the construction of buildings must have properties resulting in a low probability of injury or illness to persons not in close proximity to a fire source (PR).

C3.5 Buildings must be designed and constructed so that fire does not spread more than 3,5 m vertically from the fire source over the external cladding of multi-level buildings (PR).

Subclause C3.5 applies to:

a) buildings with upper floors containing sleeping occupancies or other property;

b) buildings of building height >10 m.

It does not apply to importance level 1 buildings (as specified in Clause A3 of the Building Code).

C3.5 is intended to reduce the risk of flame spread via the external wall surfaces of buildings. The intention is to reduce the likelihood of fire spreading into upper floor levels or creating a hazardous situation for firefighters or occupants while escaping from the building.

C3.6 Buildings must be designed and constructed so that in the event of fire in the building, the received radiation at the relevant boundary of the property does not exceed 30 kW/m^2 and at a distance of 1 m beyond the relevant boundary of the property, does not exceed 16 kW/m^2 (PR).

C3.7 External walls of buildings that are located closer than 1 m to the relevant boundary of the property on which the building stands must either (PR):

a) be constructed from materials which are not combustible building materials;

b) for buildings in importance levels 3 and 4, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 30 min;

c) for buildings in importance levels 1 and 2, be constructed from materials that, when subjected to a radiant flux of 30 kW/m^2, do not ignite for 15 min.

Subclauses C3.6 and C3.7 work in tandem to limit the probability of fire spread to adjoining property.

C3.6 is a performance requirement that limits the received radiation at the relevant distances, while C3.7 limits the combustibility of building surfaces in order to moderate the radiation requirements from the fire source building.

In C3.6, the maximum allowable received radiation on the boundary of 30 kW/m^2 recognizes that the construction of the external walls within 1,0 m of the relevant boundary must meet the separate criteria for ignitability as required by Subclause C3.7. Therefore, the material can be expected to be able to withstand an exposure of 30 kW/m^2 at least until the fire service has arrived, providing additional resources to prevent fire spread across the boundary. Beyond 1,0 m across the relevant boundary, Subclause C3.7 does not restrict the ignitability of materials that may be used on the external wall. Therefore, the maximum allowable received radiation at these locations is set at a lower value of 16 kW/m^2. As this value may not necessarily be small enough to prevent ignition or damage to all cladding materials, it is anticipated that the fire service will provide a secondary means of preventing fire spread in these situations, if necessary.

While it is not possible to give 100 % guarantee of timely fire service intervention, the history of past fires indicates that the risk of fire spread to adjacent property is small but not insignificant (approximately 3 % of all structure fires according to NZFS Emergency Incident Statistics 2005–2010).

It should be noted that the design values for radiant flux given in this scenario and other assumptions implicit in the limiting distance method do not guarantee that fire spread will be prevented in all situations. Specifically, assumptions made such as ignoring flame projection from openings, cladding properties representing timber with 15 % moisture content, limited duration of exposure, and fire gas temperatures following a standard time-temperature curve may not be the most conservative cases. For this reason, it is anticipated that, in some instances, the fire service may also be called upon to provide a secondary means of helping to prevent fire spread.

The intention of Subclause C3.7 is to ensure that materials within 1,0 m of the relevant boundary are resistant to the level of radiation that they may be exposed to in that position. If a building is to be constructed closer than 1,0 m to the relevant boundary, then it is the responsibility of the owner to reduce the probability of fire spread by reducing the likelihood of ignition of their property. This is achieved by having more stringent requirements on the ignitability of the exterior cladding for buildings within 1,0 m of the relevant boundary. The combustibility (or non-combustibility) of materials can be assessed using AS 1530 Part 1 or ISO 1182. These test methods are severe and it can be assumed that if a material is classified as non-combustible, then there will be no ignition at heat fluxes up to 30 kW/m^2. Alternatively, the time to ignition of cladding materials can be determined using ISO 5660-1. As ordinary timber claddings will ignite in less than 15 min when exposed to 30 kW/m^2, they do not meet the performance criteria of Subclause C3.7.

C3.8 Firecells located within 15 m of a relevant boundary that are not protected by an automatic fire sprinkler system and that contain a fire load greater than 20 TJ or that have a floor area greater than 5,000 m^2 must be designed and constructed so at the time firefighters first apply water to the fire, the maximum radiation flux at 1,5 m above the floor is no greater than 4,5 kW/m^2 and the smoke layer is not less than 2 m above the floor.

C3.8 recognizes that C3.6 and C3.7 may, in some situations, be insufficient to protect other property without fire service intervention. For large, unsprinklered buildings, it is the intention to limit the maximum fire size and maximum allowable total energy level that can occur within a firecell. However, although these limits apply to all buildings, the limits set are only expected to affect large storage areas. There is no direct analytical method to determine the values used in C3.8 and, although they are noticeably larger than the 2 TJ of the previous Acceptable Solution C/AS1 (2011), the conventional explanation for that previous value was not well supported by sound engineering analysis. A number of international codes, including those of the UK, USA and Australia, were reviewed for comparative purposes. The values chosen for New Zealand are considered to be broadly comparable with these codes, even though direct comparison was limited by the differences in fire-resistive construction requirements, separation distances from boundaries, and controls on the total allowable energy. The maximum area limit of 5,000 m^2 was set based on a fire load energy density (FLED) of 800 MJ/m^2 per metre height of storage and a 5,0 m storage height.

C3.9 Buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety system intended to control fire spread (PR).

Subclause C3.9 recognizes that certain fire safety features may not respond as intended. Therefore, the failure of individual fire safety features should be considered in performance-based design. The engineer is expected to evaluate their design under a specific scenario to address this concern, as well as to specify appropriate installation and maintenance standards for fire safety systems.

B.3.2.3 Clause C4 Movement to a Place of Safety

C4.1 Buildings must be provided with (FNR):

a) effective means of giving warning of fire;

b) visibility in escape routes complying with Clause F6.

C4.2 Buildings must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a place of safety and that those occupants will not suffer injury or illness as a result (FNR).

C4.3 The evacuation time must allow occupants of a building to move to a place of safety in the event of fire so that occupants are not exposed to any of the following (PR):

a) a fractional effective dose of carbon monoxide greater than 0,3;

b) a fractional effective dose of thermal effects greater than 0,3;

c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m.

Subclause C4.3 is intended to define the minimum life safety criteria for use in performance-based fire safety design. Specifying values for the fractional effective doses (FEDs) and visibility gives a more consistent level of safety than that given by the previous qualitative description of performance. According to ISO 13571, an FED of 1,0 is taken to be the level which would render occupants of average susceptibility incapable of effecting their own escape. Since the variability of human response to toxicological insults is best represented by a distribution, we can interpret an FED of 1,0 to be the point at which approximately 50 % of occupants might be expected to be incapacitated. The Code clause requires a lower FED threshold of 0,3 and we interpret this level to correspond to the point at which approximately 11 % of the population would be susceptible to less severe exposures. Lower threshold values would reduce that portion of the population. However, there is no threshold criterion so low as to be statistically safe for every exposed occupant.

The above discussion is mainly in relation to the toxicological effects of gases on people, but we have assumed that broadly similar principles apply to the thermal effects and we have accordingly used the same threshold criterion of FED <0,3.

C4.4 Subclauses C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a firecell protected with an automatic fire sprinkler system.

Subclause C4.4 removes the performance criteria for visibility and FED thermal when it is not possible to expose more than 1 000 occupants in a sprinklered firecell. This is intended to promote the use of sprinklers in buildings and to provide closer alignment with the requirements of the Acceptable Solutions. However, it also recognizes the current limitations in accurately modelling sprinkler performance in controlling the fire and reducing the threat to life safety. Although there may be a temporary increase in smoke production when a sprinkler activates, due to the expansion of steam generated from cooling the fire, this is quickly controlled and the threat to the building's occupants is greatly reduced. Therefore, with sprinklers, only the FEDCO needs to be calculated unless there are very large numbers of occupants at risk. This places a practical limit on the maximum evacuation time in the rare cases where the fire may be shielded from the sprinkler or the system does not operate as designed.

C4.5 Means of escape to a place of safety in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems (PR).

Subclause C4.5 recognizes that certain fire safety features may not respond as intended. Therefore, the failure of individual fire safety features should be considered in performance-based design. The engineer is expected to evaluate their design under a specific scenario to address this concern, as well as to specify appropriate installation and maintenance standards for fire safety systems.

B.3.2.4 Clause C5 Access and Safety for Firefighting Operations

C5.1 Buildings must be designed and constructed so that there is a low probability of firefighters or other emergency services personnel being delayed in or impeded from assisting in rescue operations and performing firefighting operations (FNR).

C5.2 Buildings must be designed and constructed so that there is a low probability of illness or injury to firefighters or other emergency services personnel during rescue and firefighting operations (FNR).

C5.3 Buildings must be provided with access for fire service vehicles to a hard-standing from which there is an unobstructed path to the building within 20 m of (PR):

a) the firefighter access into the building;

b) the inlets to automatic fire sprinkler systems or fire hydrant systems, where these are installed.

C5.4 Access for fire service vehicles in accordance with Subclause C5.3 must be provided to more than one side of firecells greater than 5,000 m^2 in floor area that are not protected by an automatic fire sprinkler system (PR).

Where Subclause C5.4 applies for vehicle access, it is intended that the points should be distributed around the building and not located each side of a corner such that the same hard-standing is utilized. The purpose of this clause is to ensure firefighter vehicle access to very large unsprinklered buildings.

C5.5 Buildings must be provided with the means to deliver water for firefighting to all parts of the building (PR).

C5.6 Buildings must be designed and constructed in a manner that will allow firefighters, taking into account the firefighters' personal protective equipment and standard training, to (PR):

a) reach the floor of fire origin;

b) search the general area of fire origin;

c) protect their means of egress.

C5.7 Buildings must be provided with means of giving clear information to enable firefighters to (PR):

a) establish the general location of the fire;

b) identify the fire safety systems available in the building;

c) establish the presence of hazardous substances or process in the building.

Subclauses C5.3, C5.4, C5.5, C5.6 and C5.7 facilitate firefighter and rescue operations using methods that are conventional and easily anticipated by the fire service. It is not expected that performance-based design would be carried out in relation to the systems provided here. It would be expected that, in the unusual event of any solutions being proposed for firefighting and rescue operations that were considered "out of the ordinary", these would be discussed in detail with and agreed to by the fire service in advance.

C5.8 Means to provide access for and safety of firefighters in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems (PR).

Subclause C5.8 means that, where provided, fire safety systems including automatic detectors, sprinklers, hydrants, smoke/heat venting systems and use of fire rated construction elements shall meet acceptable standards for their design, construction, installation and maintenance to ensure that their level of reliability and effectiveness are appropriate for the particular application.

B.3.2.5 Clause C6 Structural Stability

C6.1 Structural systems in buildings must be constructed to maintain structural stability during fire so that there is (FNR):

a) a low probability of injury or illness to occupants;

b) a low probability of injury or illness to fire service personnel during rescue and firefighting operations;

c) a low probability of direct or consequential damage to adjacent household units or other property.

C6.2 Structural systems in buildings that are necessary for structural stability in fire must be designed and constructed so that they remain stable during fire and after fire when required to protect other property taking into account (PR):

a) the fire severity;

b) any automatic fire sprinkler systems within the buildings;

c) any other active fire safety systems that affect the fire severity and its impact on structural stability;

d) the likelihood and consequence of failure of any fire safety systems that affect the fire severity and its impact on structural stability.

C6.3 Structural systems in buildings that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after fire (PR).

C6.4 Collapse of building elements that have a lesser fire resistance must not cause the consequential collapse of elements that are required to have a higher fire resistance.

B.4 Bibliography

[1] DBH. "Clauses C1-C6 Protection from Fire," Department of Building and Housing, Wellington, New Zealand, Apr. 2012

[2] MBIE. "C/VM2 Verification Method: Framework for Fire Safety Design for New Zealand Building Code Clauses C1-C6 Protection from Fire," The Ministry of Business, Innovation and Employment, Wellington, New Zealand, Jul. 2014

[3] MBIE. "Commentary for Verification Method C/VM2," The Ministry of Business, Innovation and Employment, Wellington, New Zealand, Dec. 2012

Annex C
(informative)

Example of fire safety design objectives and functional requirements in Japan

C.1 Foreword

The fire protection measures of buildings in Japan have been controlled for many years according to the provisions in the Building Standards Law (of Japan) (BSL), the Fire Service Law and other related regulations. These provisions are mostly so-called prescriptive standards, which prescribe some of the acceptable solutions of building fire safety measures in terms of kinds of permissible materials, fire resistance ratings of structural members, designs of equipment, dimensions of spaces and so forth.

The reform of BSL in 1998 to 2000 partially introduced performance-based standards, i.e. the verification methods for evacuation safety and for fire resistance performance. However, BSL still retains prescriptive structure as a whole. This is not the character particular to the Japanese building codes, but a traditional and persistent custom of worldwide fire safety regulations. Most of the prescriptive fire safety standards were developed based on empirical judgements by fire experts without solid scientific and engineering bases. Nevertheless, now that building fire loss has been stabilized at a low level for a considerable period of time, at least in developed countries, the role of such prescriptive provisions in improving the fire safety level of buildings should be duly appreciated.

However, such a traditional building control system by prescriptive regulations does not seem to be functioning well these days. The multiplication of building regulations due to frequent revisions has increasingly complicated fire safety rules and intensified the restrictions to building designs and building construction methods. The frustrations of the building community had been amplified by the nature of the prescriptive regulations, which do not explicitly state the objectives of the provisions and their targeted level of performance.

The project “Development of the Comprehensive Fire Safety Design Method of Buildings” (commonly referred to as “the Fire Safety So-pro” or “the Fire safety design 5 yrs project”) was carried out from 1982 to 1986 by the Building Research Institute (BRI), the Ministry of Construction (MOC). It may be said that the project marked the beginning of an objective-based and performance-based fire safety design method. This project aimed to establish a fire safety design method in which the performance requirements are defined instead of prescribing fire safety solutions. The expectation was that the design method could be used as an alternative to the fire safety provisions of BSL. Accordingly, the method had to take into consideration of the equivalency with BSL, which means that the objectives, the contents of requirements and the level of safety to be achieved are the same between the design method and BSL. Prescriptive codes state neither the objectives nor the performances to be achieved explicitly so it was necessary for the first to identify and re-define the objectives and functional requirements. The identification involved examining the contents and the historical development of Law of Buildings in Urban Districts, predecessor of BSL, which was enacted in 1919, as well as the current BSL, which was enacted in 1950.

The results of the Fire Safety So-pro, published as “The Comprehensive Fire Safety Design Method of Buildings”, were widely used in the fire safety designs of actual buildings through the approval system by the Minister of Construction based on Article 38 of BSL. The number of the approved fire safety designs demonstrated an impressive increase since the end of the project in 1986. However, flaws of “The Comprehensive Fire Safety Design Method of Buildings” had also been recognized. It was still deficient in terms of the many technical standards that are necessary for a building fire safety design method to be self-sufficient. It was still only able to complement the deficits of the prescriptive provisions of BSL.

Immediately after the end of the Fire Safety So-pro, an effort was started to complete the design method as a self-sufficient design system, shifting the workplace to Subcommittee for Fire Safety Design Method in the Architectural Institute of Japan (AIJ). The report was published in the title of "Recommendation on Performance-based Fire Safety Design of Buildings" in 2000.

Although the report contains extensive considerations on fire safety objectives, functional requirements, design fires, safety criteria, etc., only the parts of fire safety objectives and functional requirements are extracted and translated into English in this document.

C.2 Introduction

The cities in Japan, congested with wooden houses, have suffered frequent conflagrations in the past. Particularly, the tremendous conflagrations in Edo, the former name of Tokyo, are widely known from numerous references. The mitigation of the urban conflagrations was of prime importance for the Meiji government as well as the Tokugawa shogunate. The governments after Meiji Restoration in 1868 made various attempts to renovate Tokyo and other cities into conflagration-free cities like London and Paris. The endeavours have hardly been successful because of financial difficulties and misfortunes, such as the Great Kanto Earthquakes.

Nevertheless, the progress of urbanization and emergence of new types of buildings urged the central and local governments to develop regulations for building safety and urban planning. The fire safety provisions in the Law of Buildings in Urban Districts, enacted in 1919, put emphasis in the mitigation of urban conflagration and introduced two levels of fire zones, fire prevention zone and semi-fire prevention zone.

At the beginning, they thought that there was no fire safety problem for fire-resistive buildings although they had studied the fire regulations in advanced countries, such as the Building Code of Fire Underwriters and the Building Exit Code of NFPA, USA. It was only when Shirakiya Department Store Fire occurred in 1932, claiming 14 deaths and 47 injuries, that the need of the provisions for evacuation safety in fire was recognized. The first provisions for evacuation in a fire were introduced in the Law in 1936 for a certain limited types of unusual buildings. However, the development of hostile international circumstances around Japan hindered the development of the evacuation provisions. The threat of air raids in the cities in the mainland turned the emphasis on fire provisions to mitigate urban conflagrations once again.

The Japan-USA war exposed the cities of Japan to the dreadful incendiary bombings from B29 strategic bombers, starting with the famous Great Tokyo Air Raid on 10 March, 1945, in which over one hundred thousand of citizens were killed by the conflagrations caused by the bombing. Many other cities were also devastated to ashes by air raid fires. When the war ceased, 20 million of citizens, or 30 % of the population at that time, had lost their houses. The urgent and critical need for the government was to provide houses for the citizens. Only low-quality houses could be provided due to the despairing shortage of construction materials and this revived conflagrations in many cities over the country. In the occupation period, BSL was enacted in 1950 under the direction of General Headquarter of the occupation force, with significant change in the administration system of the building regulation, but basically following the technical contents in the Law of Buildings in Urban Districts. After having experienced tremendous number of devastating urban fires, the main concern of the provisions remained to be their mitigation.

Since the high economic growth period in 1960s, when the number of buildings increased, building fires causing serious damage began to occur frequently, culminating in the Sennichi-mae Department Store Fire in 1972, claiming 118 deaths, and Taiyo Department Store Fire in 1973. In response to these serious fire disasters, BSL was repeatedly amended to strengthen the fire safety provisions. This complicated the fire rules further. As the building communities were increasingly voicing frustrations about the severity and complexity of the fire safety provisions, the Ministry of Construction (MOC) launched the 5-year research project called "Development of Fire Safety Design Method". As a part of this study, the purpose and meanings of the provisions of BSL were reviewed to identify the objectives and requirements underlying the fire safety provisions of BSL. After all, the provisions of BSL are a blend of provisions from various sources, i.e. some are self-made by experts' discretion and others are adaptation from forerunner overseas codes. The objectives and requirements extracted are considered not particularly unique to BSL, but more or less common with overseas codes.

The purpose of BSL, declared in Article 1, is to stipulate the minimum standards that are necessary to safeguard the life, health and property of citizens and promote public welfare. The BSL is a compulsory law that applies to every building in the territory of Japan, like many other overseas' building regulations. Accordingly, the objectives and requirements extracted from the provisions of BSL have the nature of minimum requirements.

Needless to say, BSL was enacted through a legitimate legislative procedure. This reflects the consensus of people, not only of Japan but of the counties that had developed fire safety codes in advance, on what should be done, how and to what extent, for fire safety of buildings. Even if empirical, it is not wise to disregard the lessons that people have learned from a number of historical tragedies of building fires. The purpose of identifying the fire safety objectives and functional requirements is to disclose and explore more effective use of the wisdom for fire safety embedded in building codes.

C.3 General

C.3.1 Purpose

This "Recommendation on Performance-based Fire Safety Design of Buildings" (called also as "the Recommendation on fire safety design", or more simply "the Recommendation" in the following) defines the requirements for fire safety of a building and presents the technical standards for the verification of compliance of actual designs of buildings with the requirements[1)]. The ultimate purpose of the Recommendation on fire safety design is to contribute to the realization of buildings that are more economical while retaining equal or higher level of fire safety performance compared with those buildings designed according to the Building Standards Law (of Japan).

C.3.2 Scope

C.3.2.1 The Recommendation addresses the features of building designs to prevent unreasonable infringements of life, property and other rights guaranteed to the people due to fires caused without one's own intention or serious fault.

C.3.2.2 The Recommendation states the requirements that structure, element, material, space, site and facility of a building have to be satisfied for fire safety and prescribes the technical standards for the compliance verification with the requirements.

C.3.2.3 The Recommendation deals with mandatory requirements and technical standards for fire safety of building, like those set out by the Building Standards Law (of Japan), but does not deal with those that might be voluntarily introduced by building owners for the protection of their own property.

C.3.2.4 The requirements and technical standards prescribed in this Recommendation are intended to ensure the minimum level of fire safety performance of a building concerning the safety and rights of the general public, but not to guarantee a sufficient level of fire safety.

C.3.2.5 Buildings envisaged by the Recommendation are usual buildings whose fire risk or character of occupants is only ordinary, such as those for residence, accommodation, assembly, retail, business, medical treatment, education, eating and drinking, exhibition, entertainment, and amusement. Buildings with special uses or special conditions in use, such as buildings with extraordinary fire hazardous condition requiring strict fire safety managements, are out of the scope.

C.3.2.6 The Recommendation assumes as a premise that the essential conditions concerning fire safety that are presented at the stage of the design of a building are to be maintained during its use as well.

1) The technical standards are omitted in this example.

C.3.3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

C.3.3.1

escape route

route planned for occupants at a place in a building to escape safely to a final place of safety in the event of fire

C.3.3.2

evacuation plan

plan for safely evacuating the occupants in a building in the event of fire

C.3.3.3

firefighting activity

activity by fire brigades associated with the search and rescue of occupants remaining in the building and extinguishing fires

C.3.3.4

firefighting base

space for fire department operation from which a fire brigade is dispatched for search and rescue of occupants and suppression of fire

C.3.3.5

fire prevention district

fire zone that is designated in an urban area by the Urban Planning Law of Japan, in which a high level of fire resistance performance is required for buildings by the Building Standard Law of Japan to mitigate fire spread in the event that a conflagration occurs

C.3.3.6

fire safety design

design of a building and building elements to ensure fire safety objective

C.3.3.7

fire safety objective

basic purpose that must be accomplished by a fire safety design

C.3.3.8

functional requirement

verbal statement of the conditions that building design must meet to accomplish a fire safety objective

C.3.3.9

individual building

building that is separate from other buildings or a part of a building that is separated from the other part of the building with adequate means to prevent the fire hazard to and from the other part

Note 1 to entry: Recent buildings have become increasingly larger in scale, and more mixed in use and function, thereby complicating the fire safety designs. If a large and complex building can be divided into such multiple parts that are independent from each other with respect to fire safety, the fire safety design of the building will be made clearer and simpler. When a building is divided into multiple parts such that each part does not affect the other part in case of fire, then the fire safety requirements can be applied to each part independently as if it were an individual building.

C.3.3.10

prevention of fire spread to other buildings

measures taken at the building of fire origin to prevent fire spread to other buildings

C.3.3.11

prevention of fire spread from other buildings

measures taken at the building of non-fire origin to prevent damage by fire spread from another building caught in a fire

C.3.3.12

refuge

final destination of evacuation, where complete safety from fire is assured for the occupants

C.3.3.13

route to a firefighting base

route to reach a firefighting base from the place where fire engines are stationed

C.3.3.14

semi-fire prevention district

fire zone that is designated in an urban area by the Urban Planning Law of Japan, in which a certain level of fire resistance performance is required for buildings by the Building Standard Law of Japan to retard fire spread in the event conflagration occurs

C.3.3.15

the third party

natural or juridical person whose life, livelihood or management is separate from the person concerned

C.3.3.16

trunk road for urban disaster

road that is expected to be a main route for the evacuation of city residents and the traffic of emergency vehicles for firefighting, first aid, rescue, etc., in the event of an urban conflagration

C.3.3.17

urban disaster prevention base

a district that is expected to serve as a base for refuge of city residents and activities for firefighting, first aid, rescue, etc., in the event of an urban conflagration, such as a large governmental or commercial district consisting of fire-resistant buildings, a large park or green area, etc.

C.3.4 Symbols and abbreviated terms

BSL Building Standards Law (of Japan)

FSD fire safety design of a building

FNR functional requirement

P-B performance-based

OBJ objective

C.4 Outline of performance-based fire safety design

C.4.1 Principle and structure of fire safety design

This Recommendation on fire safety design is basically made based on the following principles and framework.

a) **Maintaining the equivalency to the fire safety provisions of BSL**

The Recommendation intends to ensure that the performances on fire safety are equivalent to the levels attained by complying with the provisions of the BSL. Therefore, the requirements and the technical standards on fire safety presented in this Recommendation aim at the same contents and safety levels as those of the BSL, despite the difference in the expressions.

b) **Hierarchical structure of requirements**

In the Recommendation, the fire safety objectives and fundamental requirements are explicitly stated and technical standards are provided for the compliance verification with the requirements. The technical standards are basically expressed by concrete numerical values or formulae so that the compliance of a specific building design with the corresponding requirement can be judged without ambiguity.

c) **Use of performance-based standards**

The fundamental requirements are further broken down into more concrete and detailed functional requirements, and technical standards are provided to each of them for the compliance verification. The technical standards may include prescriptive standards, but for wider flexibility in building designs, as many performance-based standards as possible are developed and incorporated into the technical standards.

C.4.2 Functional requirements for fire safety of buildings

The fire safety objectives and functional requirements were extracted by examining the provisions of the BSL, the related regulations, the explanatory documents by the Ministry of Construction (MOC), and the historical backgrounds of the laws. These are summarized below as follows:

I. REQUIREMENTS FOR FIRE SAFETY OF INDIVIDUAL BUILDINGS

- I-1 Prevention of Fire Occurrence
- I-2 Exclusion of Fire Hazardous Materials
- I-3 Assurance of Life Safety
    - I-3.1 Adequate evacuation plan
    - I-3.2 Limitation of fire hazardous building materials
    - I-3.3 Assurance of safe refuge
    - I-3.4 Assurance of safe evacuation route
- I-4 Assurance of the Third Parties' Property
    - I-4.1 Prevention of fire spread to the third party's building
    - I-4.2 Prevention of hazardous collapse onto the third party's building
    - I-4.3 Prevention of fire spread to the third party's space
    - I-4.4 Assurance of reusability of building after fire I-5 assurance of fire brigade operation
    - I-5.1 Ensuring firefighting bases
    - I-5.2 Ensuring access routes to firefighting bases

I-5.3 Control of fire size

II. REQUIREMENTS FOR FIRE SAFETY OF URBAN DISTRICTS

II-1 Building in Fire Prevention Districts

II-1.1 Breaking fire spread in urban districts

II-1.2 Protecting trunk roads for urban disaster management

II-1.3 Protecting urban disaster management bases

II-2 Building in Semi-Fire Prevention Districts

II-2.1 Retardation of urban fire spread

C.4.3 Standards for compliance verification

Performance-based (P-B) standard is the most desirable type of standards in P-B Fire Safety Design (FSD) in view of unmistakable compliance verification and flexibility in building design. However, it is practically impossible to construct all the technical standards for compliance verification as P-B standards. In addition, some standards that are converted into P-B standards may only result in complicated verification procedures without contributing meaningful benefit to fire safety design. Such standards should be simplified into prescriptive standards with a margin of safety.

The priority here is to provide at least one standard in any type to each of corresponding requirements so that the Recommendation can stand alone without depending on existing regulations. Consequently, several types of acceptable safety criteria are introduced as follows:

P: Performance criterion

C: Complementary semi-performance criterion for convenience of verification

S: Specification criterion

D: Deemed to satisfy criterion

E: Expert judgement, which trusts the discretion of fire experts or building official

Of these types of criteria, expert judgement (E) should be converted into other type of standard as soon as the relevant knowledge matures, because it is not desirable to leave the safety criteria, which must be equitable in principle, to personal judgement. However, this problem may be minimized if the capacity of judgement is limited to the authority in charge or the officially approved evaluating bodies. Considering the incessant progress of building technology, it will be unavoidable that a certain portion of standards will always remain at the discretion of appropriate experts.

C.4.4 Performance-based criteria

A performance-based criterion is expressed by a combination of a design fire condition and an acceptable safety criterion. In most cases, a complementary criterion is expressed likewise. The design fire condition here involves not only a design fire source, but also an associated fire scenario, e.g. occupant load, door opening and closing, success or fail of smoke control actuation. The level of fire safety cannot be determined by design fire or safety criterion alone. A severe design fire with a loose safety criterion and a loose design fire with rigorous safety criterion may result in a similar level of safety.

C.4.5 Predictive calculation methods for fire behaviour

To make use of the technical standards for compliance verification, calculation methods for predicting various aspects of fire behaviour are necessary. The calculation methods are the tools for verification like fire tests are, so the predictions need not to be very accurate but only have to be conservative. In this sense, a number of calculation methods now existing may be used with proper cautions of their limitations and consideration on adequate safety factors. However, such calculation methods should be assessed by peer review or by the comparison with some established benchmark calculation methods, for assuring the conservativeness.

C.5 Fire safety objectives and functional requirements

This clause describes the fire safety objectives (OBJ) and functional requirements (FNR) that were identified from the fire safety provisions in BSL and other relevant regulations.

C.5.1 Fire safety of individual buildings

C.5.1.1 OBJ I-1 Prevention of Fire Occurrence

FNR I-1.1 Materials or equipment fixed to a building shall not be installed in such a way that daily use of fire or heating appliances, or slight fault in handling thereof, can easily cause a fire.

NOTE Most of the fire safety measures are equipped in a building for mitigating potential hazards to life or the third party's rights assuming that a fire occurs in the building. Nevertheless, prevention of fire occurrence is still important. Small or large, occurrence of fire itself is already a disturbance to the public peace and order. Therefore, fire brigades and police are dispatched for early suppression and investigation of fire cause, including relationship to a crime. Also, fire prevention bylaws prohibit such deeds as to excessively increase the risk of fire. Therefore, it is necessary to remove as best as practical the building-related potential fire sources that can easily result in a serious fire.

However, the items that ignite first in fires are mostly stored commodities, so building materials or components are rarely responsible for fire occurrence. Nevertheless, where open flame is used daily, e.g. in a kitchen, it will be necessary to impose restrictions on combustibility of the interior materials, etc. located close to the fire.

In addition, if there were not any restriction to interior finish in the general part of building, there will be no ground to limit even the usages of extremely flammable materials, which can ignite by a trivial misuse of fire.

Note that what is limited here is not materials itself but only the way they are used, which connotes that flammable materials can still be allowed, provided that appropriate measures are taken to prevent its ignition, such as covering its surface by non-combustible material.

The so-called slight faults here are sorts of improper handling of fire that can happen rather frequently in everyday life, such as forgetting to extinguish a stove or overheating cooking oil in a kitchen, or the careless dropping of a lighted cigarette in a living space.

C.5.1.2 OBJ I-2 Exclusion of Fire Hazardous Area

FNR I-2.1 Parts of a building which store extremely hazardous substances, such as flammable or explosive materials, shall be provided with adequate measures, according to the level of the potential hazards, to prevent a fire that occurs therein not to spread to the other parts of the building, and that a fire that occurs in another part of the building does not spread thereto.

NOTE Part of a building where extremely dangerous substances are stored or handled is separated from ordinary parts of a building by firewalls, etc. Otherwise, should an accident occur, it can cause serious hazards to extensive areas of the building. According to the BSL, a building which stores or handles over a certain quantity of designated hazardous matters has to be fire resistant or semi-fire resistant. The requirements here basically follow such provisions. Ideally, it may not always be necessary to employ such a prescriptive measure like fire walls, but it can be possible to use appropriate measures according to the specific nature of hazardous substances. However, as there are tremendous kinds of hazardous substances, whose natures of hazards are different from one to another, it is practically impossible for building designers or engineers to have sufficient knowledge for taking efficient safety measures. The practical and efficient measures for the storage or places of handling for almost all the hazardous substances are prescribed in detail in the Fire Service Law, Explosives Control Law or Act for High Pressure Gas Safety, etc., so it will be most appropriate to follow these regulations.

Once a building complies with this requirement, it is not necessary to care about such particularly dangerous substances but only sufficient to consider normal combustibles.

C.5.1.3 OBJ I-3 Assurance of Life Safety

NOTE 1 Without doubt, life safety is the most important objective of fire safety design of building. In fire safety provisions of building codes, the primary means for securing life safety is to require adequate evacuation routes. In other words, life safety and evacuation safety mean almost the same in building fire. It can certainly be the most effective and realistic means for safe evacuation in fire of a building to provide the evacuation routes to the ground outside of a building. This strategy is likely to continue into the future. However, as buildings become increasingly large and tall, there can be the case that an evacuation plan is neither defensible nor effective without considering a refuge space within a building.

FNR I-3.1 Adequate evacuation plan

FNR I-3.1.1 A concrete evacuation plan for the event of fire shall be taken into consideration in the design of a building.

NOTE 2 Fire provisions in BSL prescribe standards on the capacity and layout of evacuation routes and on various facilities to protect or support evacuation in case of fire, but they hardly indicate how the evacuation is carried out in the event of fire. As a result, building users draw up an evacuation plan after the completion of the building, considering the features of evacuation facilities and other safety systems that happen to be equipped by the design. However, it will be too difficult to effectively design the facilities and systems for evacuation safety unless an evacuation plan is presented prior to the design. Hence, it is required to draw up a concrete evacuation plan at the stage of designing of a building, taking into account the characteristics of the use and the occupants of the building.

FNR I-3.1.2 The evacuation plan of a building shall ensure the safety from fire for the entire occupants normally expected in the building.

NOTE 3 There will be no dispute that an evacuation plan covers all occupants. The “occupants normally expected” in each space must not be assumed only from the nominal use of the space, but from the actual manner of its use. For example, a sport facility in nominal use can be frequently used for various conventions and entertainments, in which case, the number and the characteristics of the occupants will vary from one event to another.

On the other hand, it may be insignificant to consider any occupant for normally unoccupied rooms such as a machine room, in which only infrequent entrance occurs for maintenance. For another example, a meeting room in an office building can be used occasionally for a small party, but it will not be necessary to require the same level of exits as an assembly room. The standard occupants load factors are prescribed for the space uses whose average conditions of occupants can be presumed by common sense. However, the designer of a building, who directly contacts with the client, is in the best position to accurately grasp the actual condition of the building, so bears responsibility in deciding adequate design occupant load.

FNR I-3.1.3 The evacuation plan of a building shall function effectively at whatever time of day a fire may occur.

NOTE 4 Conditions of use and management of a building change every day and hour. However, it is too difficult to check if an evacuation plan works effectively in every conceivable condition, so it is practically inevitable to select a certain number of scenarios that can represent particularly disadvantageous conditions. Then, due attention must be paid not to miss any important scenario in which the evacuation plan may fail to work. For example, in case of an office building, a scenario of a fire during working hours may seem most disadvantageous because the occupant load is at the highest during this period, but it can be advantageous in the sense that a fire can be perceived quickly. On the other hand, a fire after normal working hours, when some of the offices in a building are already vacant, can cause more difficult situation than daytime in view of the delay of fire perception, even if occupant load may be lower.

FNR I-3.1.4 An evacuation plan of a building in fire shall be practicable when the associated factors, such as the characteristics of occupants, space geometry, utilization, management, operations, and fire detections/alarm systems, etc., of the building are fully taken into consideration.

NOTE 5 An evacuation plan for a building must be practicable so that it can be readily and realistically put into practice in the event of a real fire in the building. For an exaggerated example, an evacuation plan is unrealistic if it expects that all hospitalized patients evacuate by themselves through stairs at normal walking speed, or that occurrence of a fire is immediately detected in a building in which neither smoke detector nor watcher is provided. When an evacuation plan is worked out, the critical conditions to put it into practice in an actual fire must be confirmed one by one.

FNR I-3.2 Limitation of fire hazardous building materials

FNR I-3.2.1 Fire hazardous materials, such as those that are extraordinarily flammable or have the potential to generate extremely toxic gases, shall not be used in spaces that admit people who are ignorant of the potential danger thereof unless proper prevention measures are taken.

NOTE 6 It can be unavoidable to use some ignitable or flammable materials in spaces for special purposes, such as some sort of laboratories. However, as the users of such spaces are limited to particular professional members, it is possible to get them to fully understand the danger and the precaution for it. In usual spaces of building, however, it cannot be expected that the occupants have any professional knowledge about building materials so they do not know how easily they ignite, how they burn and what kind of toxic gases they can produce. In spaces admitting the general public, who are basically ignorant of the fire hazard and not particularly trained for safety, it is anticipated that a certain extent of careless deeds can occur. The objective of this requirement is to prevent that a fire caused by such a trivial misdeed rapidly develops to result in a grave tragedy in evacuation before various safety systems equipped in a building, such as evacuation facilities or smoke control facilities, begin to take effect.

A building is constructed for its own normal time functions. Although life safety from fire is an indispensable requirement for any building, too heavy economical burden due to excessive demand to fire safety provisions can cause difficulty in running the building. Actually, fire safety provisions of any country have taken into account economical restraint, as well as assurance of an appropriate level of safety, so limit their requirements within minimum necessity. Since it is too difficult to guarantee fire safety with such minimum measures against an extraordinarily severe fire condition, it is necessary to remove the risk of such a severe condition to occur by means of restricting the use of hazardous materials. If the existence of remarkably hazardous materials must be considered, the level of requirements for evacuation facilities, etc. will be raised as much. This would be enormous societal waste since the raised requirements are imposed to all the buildings in the society. This requirement has a role to reduce the heavy demand to various fire safety measures of buildings.

FNR I-3.3 Assurance of safe refuge

FNR I-3.3.1 A building shall be provided with a refuge as the final place of safety for evacuation of occupants in fire.

NOTE 7 Because the danger of a fire is usually limited within a building or its neighbourhood at most, and a building is normally erected on the ground, it is sufficient and practical as the life safety measures in fire to evacuate occupants to the outdoors. Therefore, the existing code has implicitly assumed that the final destination of escape in fire is the outdoors and has only prescribed the provisions for the escape route inside of a building. However, for high-rise or large-scale buildings, which are now increasingly popular, evacuating occupants to the outdoors may not be unconditionally practicable considering the time required for evacuation. It is the first step in designing the means of escape of a building to decide the place of final safety.

FNR I-3.3.2 A refuge shall be set up, in principle, at a place where evacuees can freely walk away from the danger of fire whenever necessary, such as a public road. However, a refuge is allowed on the site or inside of a building if evacuation to outside of the building cannot be completed within a reasonable time relative to the time of fire development.

NOTE 8 It is an implicit premise for a majority of buildings that the final place of safety is a public street. A public road is the first priority as the refuge in case of fire, since it can ensure the safety most certainly. However, in high-rise or large-scale buildings, there may be the cases in which the evacuation time to a public road is estimated to be too long relative to the time of fire growth. Also in hospitals, etc., a significant time can be necessary to get many patients to evacuate by a limited number of assisting staff. In such cases, it may be rather safer to plan a refuge within the building rather than at the outdoors. Also, a final refuge on the site can be a possibility when a building site is spacious enough.

However, a refuge prepared in a building will be, more or less, inferior to a public road in terms of the level and the reliability of safety. After all, a refuge inside a building is regarded as the last resort when the evacuation to a public road is too difficult.

FNR I-3.3.3 A refuge shall allow evacuees therein to be free from any danger due to fire such as smoke, flame, radiant heat, damage or collapse of the building.

NOTE 9 When a refuge is planned on a site or in a building, safety from all sorts of hazards due to fire such as smoke or heat, etc. is verified so that its safety level is sufficient for a refuge.

FNR I-3.3.4 A refuge shall assure physiologically tenable conditions for evacuees.

NOTE 10 A refuge can be psychologically inadequate as a space for some long-term stay even if it is free from direct danger from a fire. The psychological problem is particularly caused by the deterioration of air quality in a refuge when a large number of evacuees are confined in a small space. The tenability issue can also involve psychological aspects, but its quantitative evaluation is difficult, so the requirement here only addresses the physiological aspect.

FNR I-3.3.5 In the case of an evacuation plan that changes refuges according to fire location, the plan shall be simple enough not to cause any complication or confusion in conducting the evacuation as planned.

NOTE 11 An evacuation plan that changes the refuge according to the fire location can be adopted especially in the case when the refuge is set up in the building. An example of this concept is a horizontal evacuation in a hospital ward, i.e. the ward is divided into two or more areas by fire partitions and the patients in the block of fire origin are evacuated to the other block. Such an alternate evacuation plan is only possible when reliable staff is available and the evacuation system has been fully understood by them through periodical practices.

FNR I-3.4 Assurance of safe evacuation route

FNR I-3.4.1 Evacuation routes shall be continuous and straightforward to a refuge from every place in a building at which occupants are usually expected.

NOTE 12 An evacuation route is a series of spaces through which evacuees reach a refuge. A route that includes an impassable part for pedestrians cannot be deemed as continuous. A space in which fire risk is not negligible, such as a living room, is not included in an evacuation route that is commonly used by evacuees from different rooms. In addition, the evacuation route is readily recognized by evacuees. The evacuees in a fire can be in a kind of panic when negotiating exits to the safe place. Therefore, evacuation routes are as simple and clear as practicable, such that occupants are naturally led to a refuge through corridors and stairs after exiting a room. Such an escape route as a corridor with many branches or dead ends, or a staircase that ends at an intermediate floor so that further search for another path is required to continue the descent is, in principle, avoided. However, for types of buildings that admit only specific occupants who are familiar with the building spaces, such as apartment houses or office buildings, this requirement for clarity of evacuation routes can be less rigorous than buildings admitting the general public.

FNR I-3.4.2 An evacuation plan of a building shall be schemed to ensure at least one practicable evacuation route for all the occupants normally expected in the building no matter where a fire may break out unless the possibility of fire occurrence thereat is negligible.

NOTE 13 Giving redundancy to reinforce reliability of safety systems is a common practice not only for building fires, but for various safety issues. The “two or more escape directions” concept, which has been deemed to be important in evacuation plan for building fires, is an example of such redundant safety systems. Fire codes in most countries reflect this concept in the form of the provisions of common path length, dead end length and the requirement of two or more exits, etc. The essential meaning of the “two or more escape directions” concept is to ensure at least one evacuation route wherever a fire may break out. Generally, it is a good practice to arrange two or more escape routes in different directions, but only one evacuation route can be acceptable depending on the possibility of fire occurrence or the level of reliability of the only route.

FNR I-3.4.3 An evacuation route, including its width, shape, structure, facility, etc., shall be designed to enable the smooth evacuation of occupants in fire.

NOTE 14 It is necessary for a quick and smooth evacuation that each part of an evacuation route, such as exit, corridor and stairs, to have adequate capacity or width for the number or the characteristics of occupants. Also, structural strength, shape, material, design and equipment of escape routes must not cause any problem in evacuation movement, such as collapse of the path, falling, darkness, door locking, etc.

FNR I-3.4.4 Any part of evacuation route shall be free from hazards due to fire, such as smoke, flame, radiant heat, collapse and breakage, etc. during the period of the evacuation therein.

NOTE 15 Evacuees on an evacuation route must be safe from various dangers caused by fire. It is widely recognized that smoke is the most serious hazard for evacuees in building fires. This is because smoke spreads more rapidly and extensively than combustion itself. However, flames, radiant heat, collapse and breakage of building elements can also cause hazards to evacuations even though they tend to be overlooked in today's buildings, which basically comply with prescriptions of building codes. For example, fire resistance requirement to staircase walls has implicitly taken care of many such dangers. In performance-based design, where many of the conventional prescriptions are waived, it is necessary to reconsider every potential hazard that might be caused by fire.

It is sufficient for each part of an evacuation route to be safe only while evacuation is going on therein. For example, it is enough for the room of fire origin to be safe until all the occupants have exited the room, and in the corridors on the floor of fire origin, it is enough to ensure safety until all the people on the floor have escaped into the stairs.

FNR I-3.4.5 If no alternative escape route will be left for the occupants usually expected in the event a fire occurs at a particular part in a building, adequate measures shall be provided to protect the occupants from the fire within the building or to make the possibility of fire outbreak at the part negligible.

NOTE 16 It might be ideal if two or more evacuation routes could be ensured in a building in any circumstance, but in practice, it is not exceptional that such plans are unaffordable. It is often economically difficult to provide two stairs for small-scale buildings. As a result, the existing building codes allow single stairs for buildings smaller than a certain prescribed size. However, if the only staircase is compartmented by fire walls, a fire, should it occur, can be confined within the stairs, not causing fatal threat to the building occupants who might have no help but stay in rooms.

Generally speaking, the probability of fire occurrence in staircases or corridors is thought to be significantly small. Nevertheless, existing building codes require high level of safety measures to such spaces, such as non-combustible fire-resistant walls and the strict restriction of interior finishing. This is thought to be not only because these spaces are used for longer duration than other spaces for evacuation and firefighting etc., but also because the fatal influence is concerned when a fire breaks out in such a space. This requirement intends to respect the spirit of such provisions for stairs and corridors in the existing codes.

Not only stairs but also any part of a building prepares for the risk of fire therein if the fire can result in absolute loss of evacuation route for occupants.

C.5.1.4 OBJ I-4 Assurance of the Third Parties' Property

NOTE 1 The most important role of building fire codes, next to ensuring life safety, is to prevent damage to the third party's property. The BSL simply states that its objectives are "to protect life, health and property of people ...", but does not clarify whose property it means. On the other hand, this requirement clearly states that the property is that of the third party. This is because it would rather violate people's right to oblige the concerned person to protect his own property. The citizens in a free society are granted the right to exploit their own property at their own risk. It is only when the way of using the property causes troubles to the third party that the right is restricted. One can invest in fire compartments if it is beneficial to protect his own property, or he can buy fire insurance instead, or he can just be very careful for the fire prevention by himself, to make much use of his capital. On the other hand, the people's rights for property include that their property be not deprived or damaged by others unreasonably, so it is an important duty of people not to endanger others' property.

Not only property but many other rights and interests cannot be violated as well. Spread of fire to the third parties' property will cause unacceptable loss of others' interests, which includes not only tangible loss, but also many intangible things, e.g. peacefulness, memorials for family. However, it will be inevitable that the properties of the concerned parties are, more or less, affected when a fire breaks out in a building, so this requirement is limited only to the case that the degree of the infringement is significant.

FNR I-4.1 Prevention of fire spread to the third party's building

FNR I-4.1.1 A building shall not cause fire spread to buildings on others' property in the event a fire breaks out therein.

NOTE 2 According to the Civil Code, one who has damaged others' property is liable to make compensation for the damage whether intentionally or inadvertently. In case of an accidental fire, however, "the Law of Liability on Accidental Fire" waives this liability unless his fault is extremely grave. This can be because it is practically impossible for an individual to make the reparation to the damage caused to others in most cases, particularly when the spread of the fire involves a number of others' houses. Whatever the intention of the provision may be, it follows that people who suffer damages by fire spread from a neighbour cannot help but endure his misfortune. However, since the right for property is granted to the people by the constitution, it is evident that the abuse of this provision is not allowed. Though everyone is basically careful about a fire, it is a reality that fires occur with some degree of frequency by faults in everyday life. It will be reasonable to require any building to take adequate measures to prevent serious damage to others' property due to the fire that breaks out in the building.

FNR I-4.1.2 A building shall not cause fire spread to other buildings in the event a fire breaks out therein if it may seriously damage the tenant's important right or interest.

NOTE 3 Multiple buildings on a site belonging to the same owner can be rented to tenants. In such a case, if a fire that occurs in a building readily spread to another, the third parties' property and various important rights, concerning their family lives or businesses, etc., can be seriously disturbed. Therefore, even if not as strict as to others' buildings, a certain extent of measures to prevent fire spread to other buildings is required.

FNR I-4.2 Prevention of hazardous collapse onto the third party's building

FNR I-4.2.1 A building shall not damage others' or public properties, rights or interests by the collapse thereof due to fire.

NOTE 4 The structures of conventional wooden houses are not required to be fire resistant to survive a vigorous fire. In other words, a building is not always prohibited to collapse by fire. It is only when necessary from the viewpoint of evacuation, fire service operation or preventing troubles to a neighbour, etc. that a certain extent of fire resistance performance is required to a building. For example, no trouble can be caused to the neighbourhood if a one-story warehouse built on a spacious site in rural area collapses by fire, so that there will be no reason for requiring fire resistance performance to such a building as long as preventing impacts to the neighbourhood is concerned.

However, high-rise buildings in urban districts rarely have spacious sites, so an adequate level of fire-resistive performance is required for preventing hazard and impacts to the surrounding, as well as for evacuation and firefighting. On the other hand, it is, more or less, inevitable that collapse of any building causes a certain extent of damage or impact to others and the community. Even the collapse of an independent wooden house might hinder the traffic to a certain extent if it fronts to a street. However, since it is comparatively easy to clean up its debris and restore the traffic, such can be within the social tolerance limit. The level of requirement of fire-resistive performance from the viewpoint of preventing hazard and trouble to a neighbour is determined according to the degree of such nuisance.

FNR I-4.3 Prevention of fire spread to the third party's space

FNR I-4.3.1 A building that is divisionally owned by multiple natural or juridical persons shall not cause fire spread to parts of the building owned by others, in whichever part in the building a fire may occur.

NOTE 5 There are many buildings that are owned by multiple parties. A condominium is a typical example. In such buildings, fire spread to the parts of different ownership causes serious loss of others' properties, like in the case of fire spread to others' buildings. Therefore, the fire spread to the parts of different ownership must be prevented as well.

FNR I-4.3.2 A building shall not cause fire spread to the parts where others' important rights or interests are involved, in whichever part of the building a fire may break out.

NOTE 6 While a rental apartment building or a tenant office building, for example, is usually owned by a single owner, the properties stored in it belong to the tenants. Since the rights of various activities of tenants such as family life and business need be duly respected, it will be reasonable to impose a certain measure for preventing fire spread. However, the degree of the nuisance is somewhat light compared with the case of multiple ownership buildings. Also, in the case of tenant offices, whose floors are subdivided for rent, it is often difficult to partition between the different tenants by walls with high fire rating because of the frequent modifications of layouts according to the change and requests of tenants. Therefore, somewhat eased treatment will be necessary for the compliance with this requirement.

FNR I-4.4 Assurance of reusability of a building after fire

FNR I-4.4.1 A building that is divisionally owned by multiple natural or juridical persons shall not jeopardize the reuse after fire of any part owned by others, in whichever part of the building a fire may occur.

NOTE 7 A typical example of buildings that are divisionally owned by multiple persons is a condominium. Considering the case that a fire broke out in one of the dwelling units and the fire caused a fatal residual deformation of main structural members, the troubles for residents in other dwelling units will be very serious even though the fire neither spread to other's dwelling unit nor collapse of the building is caused. The same is true in a building for different use if owned by multiple persons or companies. Adequate level of fire resistance is ensured for such a building to ensure the structural stability to enable the reuse of the building after fire.

FNR I-4.4.2 A building in which others' important rights and interests are involved shall not jeopardize the reuse after fire of any part of the building used by others, in whichever part of exclusive use a fire may occur.

NOTE 8 Even in the case of a tenant building, damage to the structural stability of the whole building by a fire in a local space would seriously interrupt others' interests on life, business, etc., so some measures are considered to prevent the instability of the whole structure due to a local fire. However, the degree of the rights and interests of the third parties in such buildings is considered to be somewhat less serious than the case of a multiple ownership. This is reflected in the level of the acceptance for compliance with this requirement.

C.5.1.5 OBJ I-5 Assurance of Fire Brigade Operation

NOTE 1 Human societies have frequently suffered from fire disasters since ancient times, so people have cooperated in firefighting. As cities and buildings became increasingly large in scale, professional firefighting corpses, i.e. fire brigades, were gradually organized to assume the role to protect the communities from fires. As a result, various fire safety measures integrated in buildings now are planned on the premise of the existence of fire brigades. Actually, it is not difficult to find the evidence that the building fire safety codes in many countries take for granted the existence of fire brigades. In other words, the existence of such a firefighting organization has reduced the burden of the fire safety measures that would otherwise be required to each building, and thereby to the society as a whole. Today's buildings generally neither have self-sufficient equipment or systems to guarantee the suppression of fires or the life safety of occupants in fires, nor they have staffs specially trained for fires. If it were not for fire brigades and if each building were required to be equipped with its own measures to ensure the same level of fire safety as now, the cost would be enormous. Therefore, it is necessary for a building to prepare for the intervention of fire brigade so that its search and rescue of occupants and suppression of fire can be conducted as quickly and effectively as practicable in the event of a fire.

FNR I-5.1 Ensuring firefighting bases

NOTE 2 The "firefighting base" here does not mean a place where fire engines are stationed, but a place in or around a building from which firefighters undertake search and rescue of occupants and suppression of fire. Typical examples are lobbies and landings of stairs, lobbies of fire elevators, etc., which are actually used by fire brigades as bases fronting to fire scenes.

FNR I-5.1.1 A building shall provide spaces to be used by fire brigades as bases for search and rescue of left-behind occupants and for suppression of fire on such places as public road, site of the building, outside or inside of the building.

NOTE 3 On arriving at a building on fire, fire brigades establish bases from which they enter into hazardous areas for search and rescue of occupants and suppression of fire. The places available as the bases for such firefighting activities must be considered at the stage of design of a building to facilitate firefighting operations.

In case of a low-rise building like an independent dwelling house, streets around the building or the building site can be regarded as the bases for firefighting. For moderate high-rise buildings, a fire ladder can be a base to reach the place of fire in a building. On the other hand, in case of high-rise buildings beyond the reach of fire ladders, firefighting operation from the outside will be impossible if a fire occurs on upper part floors, so indoor firefighting bases, such as lobbies and landings of stairs, lobbies of fire elevator, etc., are indispensable. Incidentally, not a few existing buildings, even if low-rise, have the parts that are inaccessible by fire ladders. Some of such buildings may need spaces that can be used as indoor firefighting bases.

FNR I-5.1.2 Any space in a building that may admit occupants shall be within the reach of the possible search and rescue operation by fire brigades dispatched from a firefighting base.

NOTE 4 Even though an evacuation plan of a building is supposed to evacuate all occupants safely under certain typical fire scenarios, some occupants may fail to evacuate for various reasons under actual fire situations, as we see often in building fires.

Rescue of evacuees, who have failed to escape by themselves, is the first priority of firefighting operation. Since such an operation is conducted under unpredictable fire situations, it will be dangerous both for fire brigades and evacuees that the search and rescue operation takes up excessive time. If places to be searched are very distant from a firefighting base or if passages to the places are too complicated to negotiate, the time needed for the search and rescue can be too long. Even if the fire area is limited to a small part in a building, the range for search of evacuees can extend to a whole building. Hence, it is important to arrange the bases adequately in a building so that fire brigades can quickly complete the search and rescue.

FNR I-5.1.3 Any space in a building where a fire may occur shall be within the reach of the possible fire suppression operation by fire brigades dispatched from a firefighting base.

NOTE 5 It is necessary to avoid extreme difficulty in fire suppression by fire brigades. Such difficulties will be caused if the space of fire origin happens to be very distant from firefighting bases. Therefore, firefighting bases are so arranged that any space in a building is within a certain range from a firefighting base.

FNR I-5.1.4 A firefighting base shall ensure the safety of fire brigades therein and the effectiveness of firefighting operation.

NOTE 6 Above all, a firefighting base is required to be safe, because it is the front base from where fire brigades proceed into areas endangered by fire for fire suppression and search and rescue of evacuees. If the safety of a fire brigade is not ensured, effective firefighting operations is impossible. However a firefighting base is a place more or less close to a fire, so it is not always easy to ensure safety at a high level. On the other hand, a fire brigade is trained and prepared for fires and has experiences for firefighting, so it will be allowed to ease the safety criteria compared with the level for evacuees.

FNR I-5.2 Ensuring access routes to firefighting bases

NOTE 7 A "route to a firefighting base" here means a route all the way from a place in proximity of the building on fire, where fire engines stage to undertake firefighting operations, to the firefighting bases within or around the building. It can consist of a passage on the site, entrances, halls and staircases in the case of an indoor base. In the case of an outdoor base on the exterior of a building, it is interpreted as fire ladders, and in the case of a base on the site, it is the site itself.

FNR I-5.2.1 Any access route to a firefighting base shall ensure quick access to and retreat from the base for fire brigades.

NOTE 8 A route to a firefighting base must allow for the fire brigade to reach the base promptly and to retreat from the base quickly when endangered. If a fire brigade has to climb up stairs of a skyscraper carrying heavy equipment, it will waste the precious time needed for rescue and firefighting. This is the reason why fire elevators are required to high-rise buildings by BSL. Also, an actual fire can develop in an unexpected manner, so in the event a firefighting base is jeopardized, it is necessary to allow the fire brigade to abandon the base and quickly retreat. In most cases, a route that allows prompt access to a base will usually allow quick retreat from the base as well.

FNR I-5.2.2 Any access route to a firefighting base shall ensure safe access to and retreat from the base for fire brigades.

NOTE 9 A route to a firefighting base is also the life line for fire brigade communication from a front base and the main base on the ground, so it needs to be kept safe at any time during the fire. A route to a firefighting base can be shared with an evacuation route for occupants, e.g. a staircase. But the safety of such a route must be ensured during a firefighting operation, while the safety of a route for evacuation purpose alone can be ensured only during evacuation.

It might seem that a fire brigade, which approaches to the fire floor from below, is less at risk than evacuees in terms of safety, but the fire brigade must go further up to the floors above the fire floor for search and rescue of occupants, so the conditions can be more severe for the fire brigade. Needless to say, the safety of a route for exclusive use by fire brigades, such as a fire elevator, must be ensured independently.

FNR I-5.3 Control of fire size

FNR I-5.3.1 A building shall be able to restrict a fire within a size that can be suppressed by fire brigades.

NOTE 10 Not only BSL but also building codes in many other countries limit fire compartment by area, which demands building spaces to be divided by fire walls within prescribed areas. Although the purpose of this provision is not explicitly stated, it is considered that this implicitly contributes to many aspects of fire safety, such as safety of evacuation, prevention of fire spread, prevention of structural collapse, etc. However, various alternative measures are also available to accomplish these purposes depending on features of a building, not necessarily limiting compartment areas. The only irreplaceable reason for limiting the area of compartment is considered to be to help prevent fire spread beyond the capability of fire brigade. In case of low-rise buildings, such as dwelling houses, the firefighting is possible from the ground. In case of intermediate-rise buildings, fire hoses can be used from fire ladders, although firefighting from fire ladders will be more difficult than from the ground. In case of a fire in a building space beyond the reach of a fire ladder, since the access to the fire is limited to indoor routes, available firefighting devices and fire brigade will be very limited. This is considered to be the reason that BSL imposes severe restrictions to the size of fire compartment at high-rise parts of a building.

From the above viewpoint, a building does not allow a fire to spread beyond the control capability of fire brigades. A typical measure for this goal is to limit the size of fire compartment, but other measures, e.g. reinforcing fire extinguishment facilities, can be alternatives.

C.5.2 Fire safety of urban districts

NOTE Japan has experienced countless urban conflagrations that caused enormous economical and societal tragedies. To mitigate the hazards of urban conflagration, fire prevention districts or semi-fire prevention districts are designated in urban area according to the degree of congestion and character of districts, and certain restrictions are imposed to the buildings erected in these districts by BSL.

There are two types of fire prevention districts: one that is designated in a plane area, consisting of fire-resistant buildings for government offices or business facilities, etc., and the other that is designated in a strip area along a main street. The former intends to protect the district against conflagration by means of making entire buildings in the district to be incombustible, and the latter intends to break a conflagration and to safeguard evacuation routes by fire-resistant buildings arrayed in line along the street.

On the other hand, a semi-fire prevention district is always designated as a plane area in considerably congested urban district. It intends to retard the spread of conflagration and thereby to help firefighting and residents' evacuation, by means of requiring fire resistive performance to the buildings in the area, which is somewhat less severe than that for fire prevention district.

The designation of such a district is put into effect by the municipality concerned according to the procedure prescribed in the Urban Planning Law. The municipality must make the plan open to the public and hold a public hearing in the process of the designation of the plan, before the final approval by the governor of the prefecture. So it can be said that such a district is designated based on the consensus by the residents in the area concerned. Consequently, it is thought to be defensible to impose requirements not only to prevent fire spread from a building to other buildings, but also from other buildings to the building. Although it might seem unfair that the side of receiving fire spread has to pay for the prevention measure, this will result in mutual benefit. Strict measures will be required to a building to prevent the fire spread to its neighbour building if the neighbour building is very susceptible to catching fire. On the other hand, the more fire preventive the neighbour buildings are, the less restrictive measures are allowed for a building not to cause fire spread to the neighbour buildings.

C.5.2.1 Buildings in fire prevention districts

C.5.2.1.1 OBJ II-1.1 Breaking Fire Spread in Urban Districts

FNR II-1.1.1 A building in a fire prevention district shall not cause fire spread to other buildings in the event of fire, whether the fire may be originated therein or caused by fire spread from an urban fire.

NOTE 1 A fire prevention district is intended to mitigate the spread of urban fires. However, it is impossible even for a fire-resistant building in this district to eliminate the possibility of outbreak of fire in itself, or to be free from receiving fire spread from a conflagration in the surrounding area. Therefore, the mitigation of urban fire spread is attained mostly by preventing fire spread to other buildings when a building in the district is caught by fire. Typically, this requirement can be met by means of fire-resistive exterior walls and restricting openings, or keeping a certain distance from a site boundary according to the conditions of the building concerned.

FNR II-1.1.2 A building in a fire prevention district shall not be susceptible to fire spread from adjacent buildings on fire.

NOTE 2 This requires a building not to easily catch fire from an adjacent building on fire. Logically, the prevention of fire spread can be satisfied if each building complies with FNR II-1.1.1, which requires not to cause fire spread to other buildings. However, the more inferior the performance for prevention of receiving fire spread from adjacent buildings, the more difficult for a building to comply with FNR II-1.1.1. Even though technically possible, it will be more costly and inconvenient in everyday use. In a building-to-building fire spread scenario, any building can happen to be an unintentional attacker to other building, as well as a victim by adjacent building fires, so satisfying this requirement is for mutual benefit among buildings in the district.

C.5.2.1.2 OBJ II-1.2 Protecting Trunk Roads for Urban Disaster Management

FNR II-1.2.1 A building in a fire prevention district designated along a main street shall not cause serious hindrance to the traffic by its collapse on the street by fire.

NOTE Large buildings in a fire prevention district are not supposed to collapse by fire because they are required to be fire resistant by BSL. However, it can be hard to find any justifiable reason to prohibit their collapses as long as they satisfy the requirements for preventing a fire spread. For example, it seems reasonable that traditional dwelling houses, Shinto shrines or Buddhist temples, which are mostly wooden structure, are allowed to collapse if within their own sites.

If there is any reason that a building is not allowed to collapse while it satisfies the requirement for preventing a fire spread, it will be because the collapse of the building can cause serious impacts to public streets. A trunk road in a city must function as a traffic artery for evacuation of residents and for emergency vehicles in the event of an urban conflagration. A fire prevention district has the role to protect such a road, in addition to the role to break fire spread. So buildings in fire prevention districts designated along trunk roads must not fall down on a street. Note here, however, that this requirement implies that a building is allowed to collapse by fire unless onto streets or unless the hindrance to the traffic is serious.

C.5.2.1.3 OBJ II-1.3 Protecting Urban Disaster Management Bases

FNR II-1.3.1 A building in a fire prevention district that is expected to be an urban disaster prevention base shall not collapse by fire onto public spaces, such as a public road or a park, to seriously spoil the function of an urban disaster prevention base.

NOTE This requirement is to prohibit the collapse of buildings by fire in an urban disaster prevention base, which is designated at a plane area. Although BSJ does not explicitly state what sort of functions this type of fire prevention district plays in the event of a conflagration, it is suspected that such an area is expected to be a refuge for urban residents or a base of disaster management, such as firefighting, first aid, rescue, etc. In order for these functions to work, any building in such a district cannot collapse onto public spaces, such as roads and parks.

Fire prevention districts of this type are considered to contain not only main streets, but also many intermediate streets so that it can be too severe to require a building to prevent hindrance of traffic when a fire occurs in it. In such a plane area, many streets can form a network of paths so that alternative bypasses will be available for emergency response, etc. even if some of the streets are blocked by fire.

C.5.2.2 Buildings in semi-fire prevention districts

C.5.2.2.1 OBJ II-2.1 Retardation of Urban Fire Spread

FNR II-2.1.1 Any building in a semi-fire prevention district shall not cause fire spread easily to other buildings in the event of fire.

NOTE 1 This requires the buildings in a semi-fire prevention district not to cause fire spread to other buildings, similarly to FNR II-1.1.1, for buildings in a fire prevention district. However, a semi-fire prevention district is not an area that is intended to break a conflagration unlike in the fire prevention district, but an area that is intended to mitigate the severity of a conflagration by means of imposing a certain degree of fire-resistive performance to every building or house in the area. It is not easy for the congested urban districts in Japan to require a sufficient open space between the houses. The idea of semi-fire prevention district is that the slower the fire spread, the safer the residents' evacuation and the more chance to put out the fire by firefighting.

The word "easily" implies that the level of the requirement for preventing fire spread in this district will be eased compared with that fire prevention district. However, it does not mean that perfect prevention of causing fire spread to others is required to the buildings in a fire prevention district, although the word "easily" is not attached. There is no essential difference between the requirements for fire prevention district and semi-fire prevention district. It is only a matter of difference in the level of performance to prevent fire spread, which is determined by the technical standards for verification of compliance with these requirements.

FNR II-2.1.2 A building in a semi-fire prevention district shall not be susceptible to fire spread from other buildings.

NOTE 2 This requires the buildings in a semi-fire prevention district to prevent to receive fire spread from other buildings, similarly to FNR II-1.1.2, for buildings in the fire prevention district. The implication of attaching the word "easily" here is similar to FNR II-2.1.1 above.

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Annex D
(informative)

Examples of performance safety criteria for verification of compliance with functional requirements for individual buildings in Japan

D.1 Introduction

D.1.1 Technical standards for compliance verification

The fundamental requirement for fire safety is to clarify what a building has to do to achieve each of the fire safety objectives. However, functional requirements are verbal statements, which are just too general and abstract to be directly used in compliance verification practice of actual buildings. Each of the requirements has to be supplemented with objective technical standards to enable the actual compliance verification. It is these technical standards that determine the level of compliance with the requirements, or in other words, the level of fire safety. The level of compliance with the requirements should be so determined that the concerned society can accept both the safety level to be achieved and the cost demanded to achieve the level, in broad sense including restrictions to daily convenience, etc.

In view of wider flexibility of building design, it would be desirable that the technical standards are given in the form of "performance-based standards". At present, however, it is virtually impossible to replace all the prescriptive standards in the existing building codes with performance-based ones. In addition, some standards that are converted into P-B standards may only result in complicated verification procedures without contributing meaningful benefit to fire safety design, e.g. step and rise of stairs. Such standards should be simplified into prescriptive standards with a certain margin of safety.

The first priority is to provide at least one technical standard in any type, performance-based (P-B) or prescriptive, to each of corresponding requirements so that P-B fire safety design method can stand alone without depending on existing regulations. Consequently, several types of acceptable safety criteria are introduced as follows:

P: Performance criterion

C: Complementary semi-performance criterion for convenience of verification

S: Specification criterion

D: Deemed to satisfy criterion

E: Expert judgement, which trusts the discretion of fire experts or building official

Of these types of criteria, expert judgement (E) should be converted into another type of standard as soon as the relevant knowledge matures, because it is not desirable to leave the safety criteria, which must be equitable in principle, to personal judgement. However, this problem may be minimized if the capacity of judgement is limited to the authority in charge or the officially approved evaluating bodies. Considering the incessant progress of building technology, it will be unavoidable that a certain portion of standards will always remain to be left at the discretion of appropriate experts.

Specification and deemed to satisfy types of criteria are often useful and indispensable even in P-B fire safety codes. In the following, however, basically performance criteria (P) and complementary semi-performance criteria (C) are extracted, omitting most of the other types of criteria.

D.1.2 Performance-based safety standard

A performance-based safety standard is given by a combination of a design fire condition and an acceptable safety criterion. In most cases, a complementary criterion is expressed likewise. The design fire condition here involves not only a design fire source, but also an associated fire scenario, e.g. occupant load, door opening and closing, success or fail of smoke control actuation. The level of fire safety cannot be determined by either design fire or safety criterion alone. A severe design fire with a loose safety criterion and a loose design fire with rigorous safety criterion may result in a similar level of safety.

D.1.3 Performance safety criteria

Although it is possible to adjust both design fire conditions and safety criteria, it will be simpler to fix safety criteria and adjust design fire conditions alone to achieve the acceptable level of safety. The safety criteria in this document were developed based on this consideration.

D.1.4 Design fire

In a broad sense, "design fire" involves various conditions of fire. It is not only the matter of the fire growth rate and the maximum HRR, but the fire scenarios under which the design fire is assumed, including the state of fire safety systems, occupants, etc. For example, success or fail of activation of sprinkler, smoke control system or fire door will yield drastically different results in the assessment of a fire safety design of a building. Also, the considerations are necessary in determining "design fire" not only from the viewpoint of safety, but of societal acceptance of fire cost as well. The discussions on "design fire" is not within the capacity of this document but it should be made in some appropriate place.

D.2 Life safety of building occupants

The following criteria apply to the verification of compliance with:

a) **FNR I-3.3.3** (A refuge shall allow evacuees therein to be free from any danger due to fire such as smoke, flame, radiant heat, damage or collapse of the building) in **I-3.3 Assurance of safe refuge**;

b) **FNR I-3.4.4** (Any part of evacuation route shall be free from hazards due to fire, such as smoke, flame, radiant heat, collapse and breakage, etc. during the period of the evacuation therein) in **I-3.4 Assurance of safe evacuation route**.

D.2.1 Terms and definitions

D.2.1.1

indoor space

space inside of the envelop of a building

D.2.1.2

outdoor space

space outside of the envelop of a building

D.2.1.3

evacuation space

space used as an escape route or a refuge

D.2.1.4

evacuation period

period during which evacuees stay in an evacuation space on the way of escape or period during which evacuees stay in a refuge

D.2.1.5

fire room side space

space located at the side of the fire room relative to an opening or a partition on a passage of smoke propagation

D.2.1.6

evacuation side space

evacuation space located at the opposite side of the fire room relative to an opening or a partition on a passage of smoke propagation

D.2.2 Criteria for the safety of evacuees from smoke in buildings

An indoor space of a building that satisfies whichever of the following criteria during the prescribed time is deemed to be at acceptable level with regard to the safety of occupants from smoke.

D.2.2.1 Evac.Smoke.Indoor-(P.)

The smoke to which any of evacuees is exposed in the space satisfies Formula (D.1):

$$\int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1{,}0 \times 10^4 \qquad \text{(D.1)}$$

where

ΔT is the temperature rise of the smoke to which the evacuee is exposed to (K);

t_1 is the time at which the evacuee begins to be exposed to the smoke (s);

t_2 is the time at which the evacuee ceases to be exposed to a smoke (s).

In Formula (D.1), whether or not an evacuee in the space is exposed to smoke is determined by either of the conditions as follows.

a) Temperature of smoke

$$\Delta T > 0 \qquad \text{(D.2)}$$

where

ΔT is the temperature rise of the smoke in the space (K).

b) Height of smoke layer

$$S < 1{,}6 + 0{,}1H \qquad \text{(D.3)}$$

where

S is the height of the smoke layer interface from the floor of the evacuee (m);

H is the average ceiling height of the space from the floor of the evacuee (m).

NOTE It will be clear and sound as the goal of evacuation safety design of a building is that no evacuee is exposed to smoke. In many design practices, it is technically possible to accomplish this design goal by means of providing adequately designed exits and/or smoke control systems, etc.

However, it can be too difficult to achieve the above design goal under a certain fire scenarios. For such a space as a theatre or an atrium, where many occupants are expected at upper positions above the floor, it is often difficult to verify that none of them are exposed to smoke because smoke layer in a high ceiling space generally descend very rapidly at early stage. On the other hand, concentration of smoke in such an early stage is very low due to a large amount of entrained air so that evacuations in smoke will be possible for some short periods. As another example, considering a short corridor on an escaping route for which it is not cost-effective to provide any smoke control system, there can be no other evacuation scenario but to break through it even if it is filled with smoke. This performance criterion can accept such evacuation scenarios to some extent.

The main reason that this criterion does not use CO concentration but uses temperature rise only is that prediction of CO concentration is much more difficult than temperature because of ambiguity of source term. However, temperature rise and smoke concentration are associated with each other because they both change with the dilution by mixing with fresh air as smoke propagates in building space. Also, it is in consideration that temperature is supposed to be at dangerous level when CO concentration level is a problem for evacuation.

Regarding the exposure to toxic gases and temperature, the equation called Harber's law expressed as

$$(X-X_0)(t-t_0)=const. \tag{n1}$$

is often used, where X is the exposure intensity and t is the tolerance time. But it seems that the degree of the validity of this formula depends on the kind of hazards. So after some trials and consideration, it is decided that the form of formula as

$$(\Delta X)^2\, t=const. \tag{n2}$$

is more appropriate as a conservative criterion, considering exposures to elevated temperature and certain kinds of toxic gases.

In smoke control engineering area, smoke concentration diluted to 1/100 of that in a room of fire origin is said to be at acceptable level in a staircase. This may not always be valid but depends on exposure time to smoke. Supposing a high-rise building of 100 m of height, the time to go down the stairs at free walking speed is roughly estimated to be 400 s. On the other hand, assuming that the temperature rise in the room of fire origin is about 1,000 K and that the temperature decrease outside of the fire room is caused only by dilution, it follows that the temperature rise of smoke diluted to 1/100 is roughly 10 K. Smoke temperature in an actual situation is lowered by heat loss to walls, etc. in the course of its propagation in a building. Though a crude assumption, assuming the effects of the dilution and the heat loss on the temperature decrease are about even, it follows that the temperature rise of smoke diluted to 1/100 is 5 K. Using these values into Formula (n1), Formula (n3) is obtained:

$$(\Delta T)^2\, t_{EVAC}=5^2\times 400=10{,}000 \tag{n3}$$

The criterion here is the generalization of this formula for transient conditions. According to this criterion, 25 s of evacuation time is allowed if space temperature rise is 20 K (= 20 + room temperature, in °C), while only 1 s is allowed if the temperature rise is 100 K (= 100 + room temperature, in °C) or so, for example.

As for the judgement of smoke exposure to evacuees, it is taken into consideration that smoke behaviours are mostly assessed by one-layer or two-layer zone models in fire safety designs practices of actual buildings.

In the case of one-layer zone models, the judgement is made by temperature rise of the room gas because they only predict uniform temperature but do not predict smoke layer interface height.

In the case of two-layer zone models, the judgement is normally made based on smoke layer interface height predicted by a two-layer zone model. Though a two-layer zone model assumes a clear discontinuity between an upper and a lower layer, vertical temperature distribution in a real smoke layer is more or less dull so no clear cut layer interface exists. Therefore, assuming that contamination of smoke layer extends down to 1/10 of the smoke layer thickness below the predicted layer interface height and that the average height of the Japanese male is 172 cm, the condition that an evacuee is not exposed to smoke is:

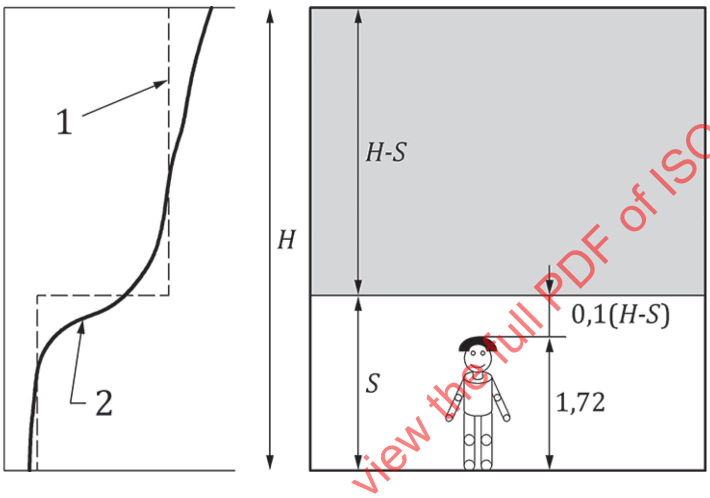
$$S-\frac{1}{10}(H-S)<1{,}72 \tag{n4}$$

that is,

$$S<1{,}56+0{,}09H \tag{n5}$$

where H is the ceiling height of the space. The value of this criterion is conservatively rounded up in the criterion.

Generally speaking, from the viewpoint of safety, the higher the smoke layer interface, the more desirable. However, ceilings of building spaces are sometimes high and sometimes low depending on use and design. If a fixed smoke layer height criterion is universally employed indifferent of the height, it can be too rigorous for low ceiling spaces, while it can be meaningless for very high ceiling spaces for the clear height is almost within error range. In this criterion, these contradictions are mitigated by the term of 0,1H.



Key

1 predicted smoke layer

2 actual layer profile

Figure D.1 — Concept of smoke layer height criterion

D.2.2.2 Evac.Smoke.Indoor-(C.1)

The smoke to which any of evacuees is exposed in the space satisfies Formula (D.4):

$$(\Delta T_{max})^2(t_2-t_1)<1{,}0\times10^4 \tag{D.4}$$

where

ΔT_{max} is the maximum temperature rise of the smoke to which the evacuee is exposed (K);

t_1 is the time at which the evacuee begins to be exposed to the smoke (s);

t_2 is the time at which the evacuee ceases to be exposed to a smoke (s).

In the above criterion, whether or not an evacuee in the space is exposed to smoke is determined by either of the conditions as follows.

a) Temperature of smoke

$$\Delta T > 0 \tag{D.5}$$

where

ΔT is the temperature rise of the smoke in the space (K).

b) Height of smoke layer

$$S < 1{,}6 + 0{,}1H \tag{D.6}$$

where

S is the height of the smoke layer interface from the floor of the evacuee (m);

H is the average ceiling height of the space from the floor of the evacuee (m).

NOTE While the above Evac.Smoke.Indoor-(C.1) is a performance-based criterion that is able to accommodate transient change of temperature rise of smoke, ΔT, to which an evacuee is exposed, this criterion is a complimentary criterion using the maximum temperature rise of the smoke, ΔT_{max}. This intends to be used more easily than Evac.Smoke.Indoor-(P.), although naturally a bit more conservative.

D.2.2.3 Evac.Smoke.Indoor-(C.2)

The smoke layer in the space concerned satisfies Formula (D.7):

$$S > 1{,}6 + 0{,}1H \tag{D.7}$$

where

S is the height of the smoke layer interface from the floor of the evacuee (m);

H is the average ceiling height of the space from the floor of the evacuee (m).

NOTE In the above criteria, Evac.Smoke.Indoor-(P.) and Evac.Smoke.Indoor-(C.1), the criteria are given in terms of temperature rise of the smoke to which evacuees are exposed, but of course $\Delta T = 0$ if evacuees are not exposed to the smoke. This complimentary criteria give the condition that evacuees are not exposed to smoke.

D.2.2.4 Evac.Smoke.Indoor-(C.3)

Whichever of the following conditions is satisfied at any of the partitions in every smoke propagation passage from fire room to the evacuation space concerned.

a) Pressure difference at openings or gaps in the partition concerned

$$\Delta P(z) > 0 \quad (h_1 < z < h_2) \tag{D.8}$$

where

$\Delta P(z)$ is the pressure difference of evacuation side space relative to fire room side space (Pa);

z is the height (m);

h_1 is the lower end height of an opening or a gap in the partition concerned (m);

h_2 is the upper end height of an opening or a gap in the partition concerned (m).

b) Smoke layer height in a fire room side space

$$S > h_2 + 0{,}1\left(H - h_2\right) \tag{D.9}$$

where

S is the height of the smoke layer interface from the floor of the evacuee (m);

H is the average ceiling height of the space from the floor of the evacuee (m);

h_2 is the upper end height of an opening or a gap in the partition concerned (m).

c) Air tightness of a partition or system of partitions along smoke propagation route

$$\frac{A_\mathrm{E}}{V} < \frac{0{,}8 \times 10^2}{\Delta T_\mathrm{s}\left(t_2 - t_1\right)^{3/2}\sqrt{\Delta P}} \tag{D.10}$$

where

A_E is the maximum equivalent opening area in the partitions on smoke propagation route during the fire (m^2);

V is the volume of the evacuation space concerned (m^3);

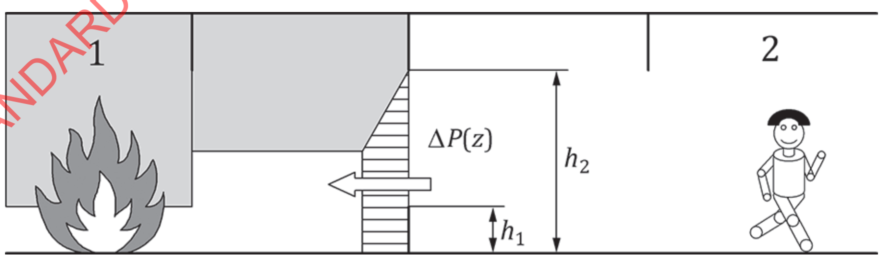
ΔT_s is the temperature rise in the fire room side space on smoke propagation route (K);

t_1 is the time when an evacuee begins to escape in the space (s);

t_2 is the time when the evacuee finishes to escape in the space (s);

ΔP is the pressure difference of fire room side space relative to evacuation side space (Pa).

NOTE 1 **Pressure difference at openings or gaps in the partition concerned.** When there is a partition wall at somewhere on a smoke propagation route from the fire room to an evacuation space, such as a corridor, a stairwell, etc., the smoke propagation into the evacuation side space can be prevented if the pressure of the evacuation side space is positive, relative to the fire room side space at any height z ($h_1 < z < h_2$) from the bottom to the top of the openings or gaps in the partition. The temperature in a fire room side space is usually higher than that in an evacuation side space. Therefore, if the pressure at the opening soffit is positive, namely $\Delta P(h_2) > 0$, the pressure at any height z ($h_1 < z < h_2$) is $\Delta P(z) > 0$. However, because the possibility of exceptional temperature conditions cannot be totally neglected, this complimentary criterion is expressed as above. The representative means to build such pressure difference is a mechanical smoke control system but may not be limited to it.



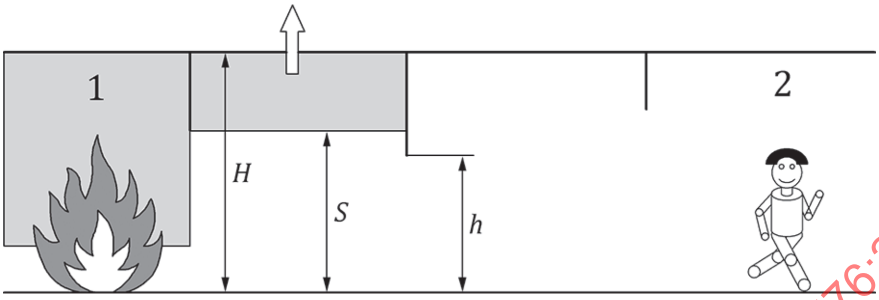
Key

1 fire room

2 evacuation space

Figure D.2 — Safety of evacuation space achieved by pressure difference

NOTE 2 **Smoke layer height in a fire room side space.** This criterion indicates another condition to prevent smoke propagation to an evacuation side space. Simply saying, this criterion means that smoke does not invade into an evacuation side space if smoke layer in the fire room side space is at higher position than the opening soffit in the partition. Incidentally, the second term in the right hand side of Formula (D.9) reflects more or less the blurred nature of smoke layer interface.



Key

1 fire room

2 evacuation space

Figure D.3 — Safety of evacuation space achieved by smoke layer height

NOTE 3 **Air tightness of a partition or system of partitions along smoke propagation route.** Let us imagine the situation that a partition or a system of partitions, with some gaps, separates spaces into the fire room side and the other in the evacuation side. Smoke will flow into the space at evacuation side through the gaps if pressure at smoke contaminated side is positive, relative to the evacuation space side. Noting that mass inflow and outflow rates for a room are generally the same at steady-state, the mass conservation in the evacuation space is expressed by:

$$M\frac{dX}{dt}=m\left(X_0-X\right) \tag{n1}$$

where

X_0 is the mass fraction of smoke in the fire room side space (-);

X is the mass fraction of smoke in the evacuation side space (-);

M is the mass of air in the evacuation side space (kg);

m is the mass flow rate of air into (= out of) the evacuation side space (kg/s);

t is the time (s).

Integrating Formula (n1) with initial condition $X = 0$ when $t = 0$ and approximating the result, we obtain

$$\frac{m}{M}t=-\ln\left(1-\frac{X}{X_0}\right)\approx\frac{X}{X_0} \tag{n2}$$

Furthermore, assuming that the temperature drop is caused only by dilution

$$\frac{X}{X_0}=\frac{\Delta T}{\Delta T_s} \tag{n3}$$

where ΔT_s is the temperature rise of the smoke contaminated space. Then, using Formula (n3) and the complimentary criteria Evac.Smoke.Indoor-(C.1),

$$(\Delta T)^2\left(t_2-t_1\right)<1{,}0\times10^4 \tag{n4}$$

Formula (n2) becomes as follows:

$$\frac{m}{M}(t_2 - t_1)^{3/2} < \frac{1{,}0 \times 10^2}{\Delta T_s} \tag{n5}$$

Letting ρ be the air density, M and m are given by

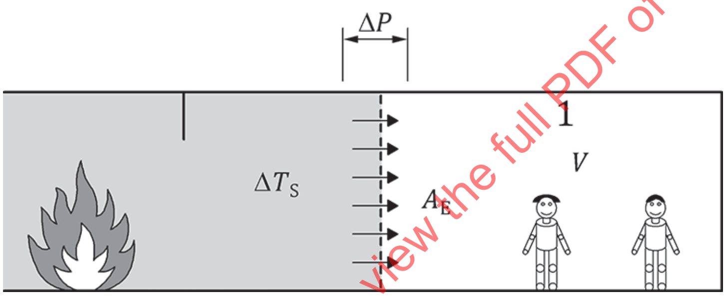
$$M = \rho V \text{ and } m = A_E \sqrt{2\rho \Delta P} \tag{n6}$$

Hence, finally

$$\frac{A_E}{V} < \sqrt{\frac{\rho}{2}} \frac{1{,}0 \times 10^2}{\Delta T_s (t_2 - t_1)^{3/2}} \frac{1}{\sqrt{\Delta P}} \tag{n7}$$

Using ρ = 1,2 and rounding up the coefficient results criterion [Formula (n3)].

Note that there may be multiple smoke propagation routes from the room of fire origin to an evacuation space depending on space layouts and needless to say, smoke propagation must be prevented at somewhere on every route. Any of a) through c) can be employed for each of the routes, but sufficient consideration is necessary on their interactions when they are combined.



Key

1 evacuation space

Figure D.4 — Safety of evacuation space achieved by air tight partition

D.2.3 Criteria for the safety of evacuees from smoke in outdoor

An outdoor space of a building where whichever of the following criteria is satisfied during the prescribed time is deemed to be at acceptable level with regard to the safety of occupants from smoke.

D.2.3.1 Evac.Smoke.Outdoor-(P.)

The smoke to which any of evacuees is exposed in the space satisfies Formula (D.11):

$$\int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1{,}0 \times 10^4 \tag{D.11}$$

where

ΔT is the temperature rise of the smoke to which the evacuee is exposed (K);

t_1 is the time when the concerned evacuee begins to be exposed to the smoke (s);

t_2 is the time when the concerned evacuee ceases to be exposed to the smoke (s).

NOTE This criterion is similar with Evac.Smoke.Indoor-(P.). However, at the outside of a building, it is difficult to generate the conditions to decide when evacuees are exposed to smoke. A typical scenario of smoke exposure of evacuees can be such that a fire occurs on a floor in an apartment building with corridors open to air and occupants on upper floors escape via the corridors which are partly exposed to smoke from openings of the fire room. In such a case, t_1 is the time at which an evacuee enters into the smoke contaminated part and t_2 is the time at which he exits the part, and more clearly, $t_2 - t_1$ is the time of travel in the smoke.

D.2.3.2 Evac.Smoke.Outdoor-(C.1)

The smoke to which any of the evacuees is exposed in the space satisfies Formula (D.12):

$$(\Delta T_{\max})^2 (t_2 - t_1) < 1{,}0 \times 10^4 \quad \text{(D.12)}$$

where

$\Delta T_{\max}$ is the maximum temperature rise of the smoke to which the evacuee is exposed (K);

t_1 is the time at which the evacuee begins to be exposed to the smoke (s);

t_2 is the time at which the evacuee ceases to be exposed to the smoke (s).

NOTE This criterion is similar with Evac.Smoke.Indoor-(C.1), although the scenarios of smoke exposure are somewhat different as mentioned in the note for Evac.Smoke.Indoor-(P.).

D.2.3.3 Evac.Smoke.Outdoor-(C.2)

The smoke to which any evacuee is exposed in the space satisfies all the following conditions:

a) As to the location of the evacuation space relative to any opening that may eject smoke in the event of fire, any of the following conditions is satisfied.

1) Height from the lower end of the opening

$$z < 0 \quad \text{(D.13)}$$

where

z is the height from the lower end of the opening (m).

2) Horizontal distance perpendicular to the opening surface

$$\frac{x}{H} > 0{,}6\left(\frac{z}{H}\right)^{1/3} + 0{,}3\left(\frac{z}{H}\right) \quad \text{(D.14)}$$

where

H is the height of the opening (m);

x is the horizontal distance from the opening that is perpendicular to its surface (m);

z is the height from the lower end of the opening (m).

3) Horizontal distance parallel to the opening surface

$$\frac{y}{H} > 0{,}3\left(\frac{z}{H}\right) \quad \text{(D.15)}$$

where

H is the height of the opening (m);

y is the horizontal distance from the opening that is parallel to its surface (m);

z is the height from the lower end of the opening (m).

b) There is no particular eave or balcony that disturbs free rise of the opening spill plume.

c) Cracks or burned through that may allow flames to penetrate are not caused on the exterior walls of the fire compartment during the fully developed fire.

NOTE Fire gases contain various harmful substances such as heat, toxic gases and smoke particles. However, after having come out to open air, the extent of their danger goes down due to the mixing with fresh air, so an evacuation space at far enough downstream of the openings of a fire room is safe enough. Since it is not easy enough for usual engineers to calculate the temperature of hot gas flows from an opening, a complementary criterion is introduced here so that hazard evaluation of an opening jet plume from a fire-resistive building can be easily treated unless the location of an evacuation space is at an exceptional position. Formulae D.13, D.14 and D.15 correspond to the domains (i), (ii) and (iii) in Figure D.5, respectively, which are not exposed to the opening jet from a fire compartment.

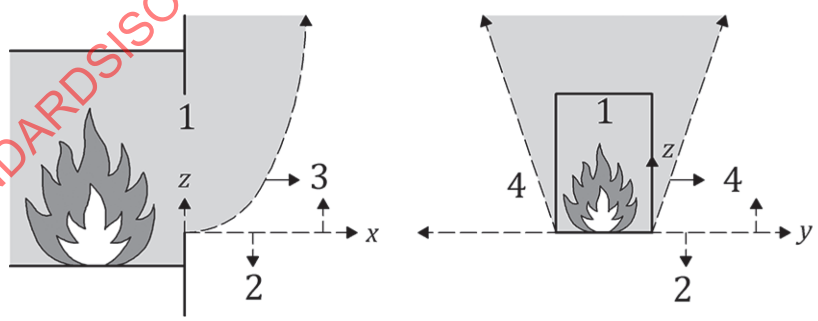
Based on Yokoi's study, an approximate formula for the trajectory of an opening jet plume can be derived as

$$\frac{x}{H} = 0{,}6\left(\frac{z}{H}\right)^{1/3} \tag{n1}$$

where *x* and *z* are the horizontal and the vertical distances from the ejecting point of an opening plume, respectively, and *H* is the height of the opening. In the criterion, 0,3(z/H) is added to the above formula, considering the diffusion of the plume, and the height *z* is taken from the lower end of opening for simplicity and conservative estimation, that is:

$$\frac{x}{H} > 0{,}6\left(\frac{z}{H}\right)^{1/3} + 0{,}3\left(\frac{z}{H}\right) \tag{n2}$$

Here, the value of 0,3 is thought to be at sufficiently safer side comparing with the values of extension of the half-width of a usual fire plume, e.g. 0,13 from Zukoski and 0,15 from Hasemi, although it is necessary to take into account that temperature rise naturally develops outside of half-width to an extent and that turbulence due to wind can cause wider diffusion of a plume.



Key

1 opening

2 Field (i)

3 Field (ii)

4 Field (iii)

Figure D.5 — Domain exposed to opening jet plume

D.2.4 Criteria for the safety of evacuees from radiant heat

A space that satisfies either of the following criteria during the prescribed time is deemed to be at acceptable level with regard to the safety of occupants from radiant heat.

D.2.4.1 Evac.Radiation-(P.)

The radiant heat to which any of evacuees is exposed in the space satisfies Formula (D.16):

$$\int_{t_1}^{t_2} I^2 dt < 2{,}5 \times 10^2 \tag{D.16}$$

with Formula (D.17):

$$I = \begin{cases} q'' - 0{,}5 & (q'' > 0{,}5) \\ 0 & (q'' \le 0{,}5) \end{cases} \tag{D.17}$$

where

q'' is the incident heat flux to the evacuee (kW/m^2);

t_1 is the time at which the evacuee begins to be exposed to the radiant heat (s);

t_2 is the time at which the evacuee ceases to be exposed to the radiant heat (s).

NOTE Consider that a wall in an important evacuation space, such as a staircase or a corridor, is made of wired glasses or metal panels. The wall might not be broken by fire but is hardly heat insulative and the room behind the wall can be a potential fire room. In the event of fire, evacuees in the evacuation space can be exposed to radiant heat from the heated wall. Whether or not such a wall can be allowed is considered to depend on the size of the wall. This criterion is applied typically to such cases, for the judgement of evacuation safety, but there can be many other cases in which radiant heat to evacuees becomes to be an issue.

When a human body is exposed to radiant heat, temperature rise of the skin causes pain at about 45 °C. Assuming a human body as a semi-infinite solid receiving constantly net radiant heat at the rate of I, the surface temperature rise, ΔT, is:

$$\Delta T = 2I \left(\frac{t}{\pi k \rho c} \right)^{1/2} \tag{n1}$$

where $k\rho c$ is the thermal inertia of human body and t is the time.

Therefore, if radiant heat becomes unbearable for human bodies when the temperature rise, ΔT, reaches a certain critical value, because of pains or skin burns for example, the following relation is expected.

$$I^2 t = const. \tag{n2}$$

$$\sigma T_{body}^4 = 5{,}67 \times 10^{-11} \times (273 + 36)^4 \approx 0{,}5\,kW/m^2 \tag{n3}$$

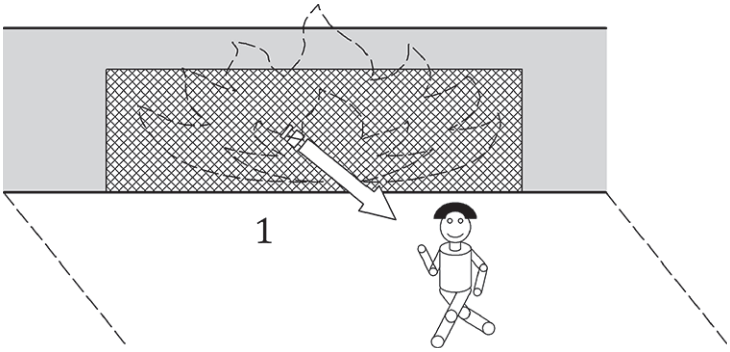
where σ and T_{body} are Stefan-Boltzmann constant and temperature of human body, respectively.

The right-hand side term of Formula (n2) is determined based on the existing experimental results with consideration of some safety margin.

Incidentally, as to the particular example mentioned above, the time for evacuees to pass the front of the heat radiating wall surface is assessed as follows, letting v be walking speed:

$$t = B / v \tag{n4}$$

The acceptable width B of a heat radiant surface such as wired glass openings can be revealed using this criteria and predicted radiant heat flux q′.



Key

1 radiant heat

Figure D.6 — Radiant heat exposure to occupant's evacuation

D.2.4.2 Evac.Radiation-(C.1)

The radiant heat to which any of evacuees is exposed in the space satisfies Formula (D.18):

$$I^2(t_2 - t_1) < 2{,}5 \times 10^2 \tag{D.18}$$

with Formula (D.19):

$$I = \begin{cases} q''_{max} - 0{,}5 & (q'' > 0{,}5) \\ 0 & (q'' \leq 0{,}5) \end{cases} \tag{D.19}$$

where

q''_{max} is the incident heat flux to the evacuee (kW/m2);

t_1 is the time at which the evacuee begins to be exposed to the radiant heat (s);

t_2 is the time at which the evacuee ceases to be exposed to the radiant heat (s).

NOTE This is a complimentary criterion in which the radiant heat flux to evacuees in Evac.Radiation-(P.) is replaced with its maximum value for safer side verification.

D.2.5 Criteria for the safety of evacuees from falling debris

A space where whichever of the following criteria is satisfied during the prescribed time is deemed to be at acceptable level with regard to the safety of occupants from falling objects.

D.2.5.1 Evac.Debris-(C.1)

Any building element and its support member satisfy the following conditions during the prescribed time if the element can cause danger to evacuees in the concerning space when it falls down.

a) The element satisfies all the following conditions:

$$T < \min.(T_{brk}, T_{mlt}, T_{ign}) \tag{D.20}$$

where

T is the temperature of the element (K);

T_{brk} is the breakage temperature of the element (K);

T_{mlt} is the melting temperature of the element (K);

T_{ign} is the ignition temperature of the element (K).

b) The support members of the element satisfy the criterion “D.3.2 Criteria for structural stability in fire”.

NOTE A refuge, evacuation route, firefighting base, etc. can be subjected to danger due to falling debris from building space on fire. Several measures are conceivable for ensuring safety of such a space from falling or flying debris. This complimentary criterion is to determine the conditions required for the measure to ensure the safety by means of endurance of building element to fire exposure.

Here, the criteria are given to a) building element and b) its support member, respectively. Their typical example is roof materials and roof truss. Many sorts of elements are conceivable as such building elements, ranging from non-combustible materials like glass to combustible materials like plastics or wood, so the mechanism of falling varies. Combustible materials, for example, do not always fall down immediately after their ignition. However, for the convenience of practical use, only critical temperature is used as the criteria for all kinds of materials.

Even if a roof element is made of fire-resistive materials, whole roof structure would fall down if the support members of the roof cannot endure the fire. So it is natural that the roof support member is required to be fire resistive too. The stability of roof supporting member can be verified by the criteria in “D.3.2 Criteria for structural stability in fire”.

D.2.5.2 Evac.Debris-(C.2)

Any position in the concerning space is in the range that satisfies Formula (D.21):

$$D > \sqrt{H} \tag{D.21}$$

where

D is the horizontally projected distance between the part that may fall down and the position in the concerning space (m);

H is the vertically projected distance between the part that may fall down and the position in the concerning space (m).

NOTE In case a refuge is somewhat remote from the building on fire, for example, no danger would reach to the occupants therein even if the fire causes falling debris. Since the knowledge is badly limited for sufficient distance to ensure safety of a space from falling debris, a crude consideration is made as follows.

The trajectory of an object that falls down simply with initial horizontal velocity of u_0 only is:

$$x = u_0 t \tag{n1}$$

$$y = \frac{1}{2} g t^2 \tag{n2}$$

where

u_0 is the initial horizontal velocity of the falling debris (m/s);

g is the gravity acceleration (m/s^2);

t is the time (s);

x is the horizontal distance (m);

y is the vertical fall down distance (m).

Therefore, letting H be the height of potential falling part from the concerning place, the horizontal distance x is given by:

$$x = 0,45 u_0 \sqrt{H} \tag{n3}$$

Though it is difficult to determine the initial velocity u_0, let us imagine the case that glass panes of the room of origin break, which is a representative of falling debris in fire. Considering the situation that force F due to the pressure difference between the outdoor and the room of fire origin is acting on a broken piece of glass with mass of m, the next formula holds

$$F = \Delta P A = m\alpha \tag{n4}$$

where α is the acceleration, A is the area of the pane piece and ΔP is the pressure difference. Letting h be the height of the window soffit from neutral pressure zone, ΔP is about the order of:

$$\Delta P \approx \Delta \rho g h \tag{n5}$$

From Formulae (n4) and (n5)

$$\alpha \approx \frac{\Delta P A}{m} = \frac{\Delta \rho g h A}{\rho_{\mathrm{GLS}} d A} \tag{n6}$$

where ρ_{GLS} is the glass density (= 2 200 kg/m^3) and d is the thickness (= 0,5 cm).

Glass pane can crack at around 150 °C but tends to stay in a window. Here, assuming that a glass pane breaks off from a window at temperature 500 °C, α = (1/15) gh is obtained. If the force, F, applies to the glass piece during the time it falls in the window jet, the duration is about the order of:

$$t \approx \sqrt{2h/g} \tag{n7}$$

Therefore, the velocity u_0 at which it leaves from the window jet becomes a:

$$u_0 = \alpha t \approx \frac{1}{15} g h t = \frac{\sqrt{2g}}{15} h^{3/2} \tag{n8}$$

Conservatively assuming the window height as 3 m, so h is approximately 2 m, the initial velocity u_0 is calculated to be u_0 = 0,83 m/s. Therefore, from Formula (n3), the horizontal distance x becomes:

$$x \approx 0,37 \sqrt{H} \tag{n9}$$

In reality, the initial velocity will not be maintained due to air friction. On the other hand, range of its scattering can be wider than expected because falling trajectory of a glass piece becomes complicated by resistance of air or influence of outdoor wind. So, the coefficient value in the criterion is about tripled.

The above discussion is limited to small falling debris such as glass pieces. On the other hand, as for heavy objects, though their initial velocities can be small and influence of wind can be trivial, their rebounding or scattering after colliding to the ground can be significant. Since such effects are far beyond any estimation method available for us, it is decided to use the same criterion. But, psychologically, the distance may not be sufficient, considering such examples as the required distance is about 3 m for a 10 m high building and 10 m for a 100 m high building.

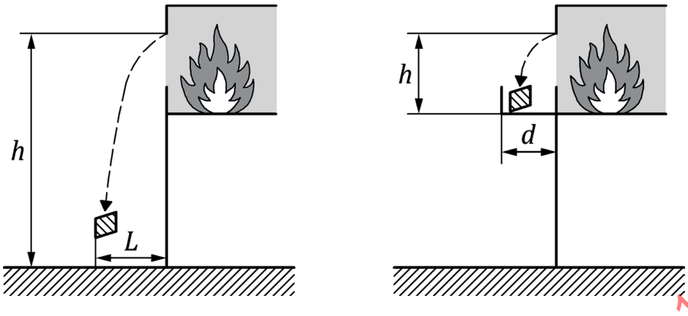


Figure D.7 — Safety from falling objects due to fire

D.2.5.3 Evac.Debris-(C.3)

Any eave, balcony or roof on the same or lower floor satisfies Formula (D.22):

$$d > \sqrt{h} \tag{D.22}$$

where

- d is the horizontally projected distance between the part that may fall down and the tip of eave, balcony or roof below the part (m);
- h is the vertically projected distance between the part that may fall down and the tip of any eave, balcony or roof below the part (m).

NOTE This criterion is based on the same consideration as the above Evac.Debris-(C.2).

D.3 Structural stability

The following criteria apply to the verification of compliance with:

a) **FNR I-3.4.4** (Any part of evacuation route shall be free from hazards due to fire, such as smoke, flame, radiant heat, collapse and breakage, etc. during the period of the evacuation therein) in **I-3.3 Assurance of safe refuge**;

b) **FNR I-3.4.4** (Any part of evacuation route shall be free from hazards due to fire, such as smoke, flame, radiant heat, collapse and breakage, etc. during the period of the evacuation therein) in **I-3.4 Assurance of safe evacuation route**;

c) **FNR I-4.2.1** (A building shall not damage others' or public properties, rights or interests by the collapse thereof due to fire) in **I-4.2 Prevention of hazardous collapse onto the third party's building**;

d) **FNR I-4.4.1** (A building that is divisionally owned by multiple natural or juridical persons shall not jeopardize the reuse after fire of any part owned by others, in whichever part of the building a fire may occur) in **I-4.4 Assurance of Reusability of building after fire**;

e) **FNR I-5.1.4** (A firefighting base shall ensure the safety of fire brigades therein and the effectiveness of firefighting operation) in **I-5.1 Ensuring firefighting bases**;

f) **FNR I-5.2.2** (Any access route to a firefighting base shall ensure safe access to and retreat from the base for fire brigades) in **I-5.2 Ensuring access routes to firefighting bases**;

g) **FNR II-1.2.1** (A building in a fire prevention district designated along a main street shall not cause serious hindrance to the traffic by its collapse on the street by fire) in **II-1.2 Protecting trunk roads for urban disaster management**;

h) **FNR II-1.3.1** (A building in a fire prevention district that is expected to be an urban disaster prevention base shall not collapse by fire onto public spaces, such as a public road or a park, to seriously spoil the function of an urban disaster prevention base) in **II-1.3 Protecting urban disaster management bases**.

D.3.1 Terms and definitions

D.3.1.1

structural stability

state of a structure at which no excessive movement and/or deformation is caused by the application of an external force thereto

D.3.1.2

long time design loading

external loads for structural design purpose that act to a structure at all time such as fixed loads and live loads

D.3.1.3

hazard to the neighbourhood

damage, nuisance, disturbance of normal order of life, etc. that are caused to neighbour persons and/or general public in the vicinity of a building

D.3.1.4

allowable stress

limit stress for structural design purpose that is determined to assure that stress caused in a structural member by external load does not exceed the yield stress thereto

D.3.1.5

yield strength

strength at which a structural member subjected to loading begins to be apart from Hooke's law

D.3.2 Criteria for structural stability in fire

A building that complies with whichever of the following criteria during the prescribed time is deemed to be at acceptable level with respect to structural stability in fire.

D.3.2.1 Struct.Stability-(P.)

Every load bearing member satisfies both of the following conditions:

a) Axial strength in fire

$$P(T) > P_D \tag{D.23}$$

where

$P(T)$ is the axial strength of the load bearing member when exposed to the fire (N);

P_D is the axial force under long time design loading (N).

b) Bending strength in a fire time

$$M(T) > M_D \tag{D.24}$$

where

$M(T)$ is the bending strength of the load bearing member when exposed to fire (Nmm);

M_D is the bending moment under long time design loading (Nmm).

NOTE Generally, in building structural members such as columns or beams, compressive stress and a bending stress are caused due to loading. Naturally, structural members are so designed as to put up with the loads in normal time. In the event of fire, however, structural members may not be able to bear the load so can collapse because of the deterioration of the effective yield strength or loss of cross-sectional areas due to temperature rise by fire heating.

There are a couple of ways to prevent the collapse of structural members by fire, for example, to protect them from the fire heating with fire insulation so to prevent temperature rise, or to design them with some margin so that they can still bear the load even if their strength is deteriorated more or less due to temperature rise. Fire resistance design for steel structures is based on the former idea and that for large section wooden structures is based on the latter idea.

This P-B criterion is so expressed as that it can be commonly applied regardless of the type of structures. Note that condition a), relating to the axial strength, is applied not only to simple compressive failure, but also to buckling failure in cases of long columns, although not explicitly mentioned.

D.3.2.2 Struct.Stability-(C.1)

In case of a steel structure, every load bearing member satisfies both of the following conditions:

a) The axial strength satisfies both of the following conditions:

1) Axial compressive strength

$$P_C(T) > P_D \tag{D.25}$$

where

T is the temperature of the load bearing steel member (K);

$P_C(T)$ is the axial compressive strength of the load bearing steel member at temperature T (N);

P_D is the axial force due to the long time design loading (N).

In Formula (D.25), $P_C(T)$ is calculated by Formula (D.26):

$$P_C(T) = A_C \cdot \sigma_y(T) \tag{D.26}$$

where

A_C is the cross-sectional area of the load bearing steel member (mm^2);

$\sigma_y(T)$ is the effective yield strength of the load bearing member at temperature T (N/mm^2).

2) Axial buckling strength in fire

$$P_B(T) > P_D \tag{D.27}$$

where

T is the temperature of the load bearing steel member (K);

$P_B(T)$ is the buckling strength of the load bearing steel member at temperature T (N);

P_D is the effective buckling force due to the long time design loading (N).

In Formula (D.27), $P_B(T)$ is calculated by Formula (D.28):

$$P_B(T) = A_C \cdot \sigma_{cr}(T) \tag{D.28}$$

where

A_C is the cross-sectional area of the load bearing steel member (mm²);

$\sigma_{cr}(T)$ is the buckling stress of the load bearing steel member at temperature T (N/mm²);

and $\sigma_{cr}(T)$ is calculated by Formula (D.29):

$$\sigma_{cr}(T) = \begin{cases} \left(1 - 0{,}4\left(\dfrac{\lambda}{\Lambda}\right)^2\right)\sigma_y(T) & (\lambda \le \Lambda) \\ \dfrac{0{,}6\sigma_y(T)}{\left(\dfrac{\lambda}{\Lambda}\right)^2} & (\lambda > \Lambda) \end{cases} \tag{D.29}$$

where

λ is the slender ratio (= buckling length / radius of gyration) (-);

$\sigma_y(T)$ is the yield stress of the load bearing steel members at temperature T (N/mm²);

Λ is the limit slender ratio at room temperature (N/mm²);

and Λ is given by Formula (D.30):

$$\Lambda = \sqrt{\frac{\pi \overline{E}}{0{,}6\overline{\sigma}_y}} \tag{D.30}$$

where

$\overline{E}$ is the Young's modulus of steel member at room temperature (N/mm²);

$\overline{\sigma}_y$ is the yield stress of steel at room temperature (N/mm²).

b) The bending strength satisfies the following conditions:

1) Bending strength

$$M(T) > M_D \tag{D.31}$$

where

T is the temperature of the load bearing member (steel member) (K);

$M(T)$ is the bending strength of the load bearing member at temperature T (Nmm);

M_D is the bending moment due to the long time design loading (Nmm);

and $M(T)$ is calculated by:

$$M(T) = Z_{px} \cdot \sigma_y(T) \quad \text{(D.32)}$$

where

Z_{px} is the plastic section modulus of a load bearing member (mm^3);

$\sigma_y(T)$ is the yield stress of the load bearing member at temperature T (N/mm^2).

2) If there is any weak part in the beam member, such as a part of bolt connection, the above bending strength shall be devaluated accordingly.

The yield stress of a load bearing member at temperature T, $\sigma_y(T)$, in the formulae in a) and b) shall be estimated by the following.

— The $\sigma_y(T)$ of SS400 and SM490, or other structural steels whose mechanical properties at high temperature are equal or superior to these, can be estimated by Formula (D.33).

$$\sigma_y(T) = \begin{Bmatrix} \bar{\sigma}_y & (T \le T_1) \\ \bar{\sigma}_y \dfrac{T_2 - T}{T_2 - T_1} & (T_1 < T \le T_2) \\ 0 & (T_2 < T) \end{Bmatrix} \quad \text{(D.33)}$$

where

$\bar{\sigma}_y$ is the standard stress of steel member at room temperature (N/mm^2);

T is the temperature of the steel member in fire (°C);

T_1 is the temperature at which the strength of steel begins to decrease (= 325) (°C);

T_2 is the temperature at which the strength of steel becomes zero (= 700) (°C).

— Yield strength of such a structural steel material whose product lot can be identified and whose properties at high temperatures are available can be estimated by multiplying 0,9 to the strength at 1 % strain in its stress-strain curve.

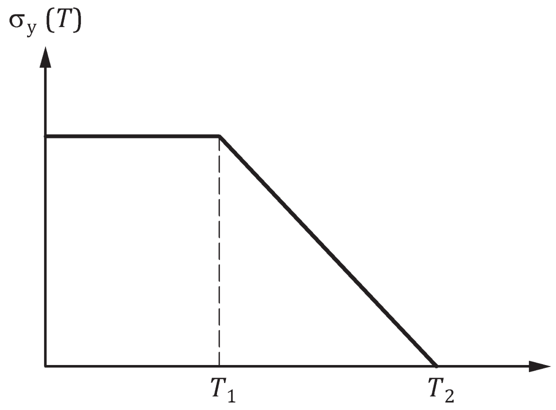


Figure D.8 — Strength degradation of steel due to temperature rise

NOTE The deterioration of strength of steel structure is mainly caused by the decrease of yield strength and Young's modulus due to temperature rise, and buckling can occur because of its large slenderness ratio. This complementary criterion is introduced to interpret the above P-B criterion Struct.Stability-(P.) more explicitly for steel structure case.

Bending moment distribution along a beam varies depending on end confinement condition of the member. In a beam confined at both ends, which is usual in building structure, bending moment is caused not only around its middle, but also around the end of member in opposite direction to that at the middle. Therefore, the above criterion for bending strength must be satisfied both at the middle and the ends of member. To make sure, temperature T in $\sigma_y(T)$, E(T), etc. does not mean fire temperature itself, but means the temperature of members due to fire heating.

D.3.2.3 Struct.Stability-(C.2)

In case of a reinforced concrete structure, every load bearing member satisfies both of the following criteria:

a) Axial compressive strength

$$P_C(T) > P_D \tag{D.34}$$

where

$P_C(T)$ is the axial compressive strength of the load bearing member in fire (N);

P_D is the axial force due to long time design loading (N).

In Formula (D.34), $P_C(T)$ is calculated by Formula (D.35):

$$P_C(T) = A_{CT} \cdot \bar{\sigma}_c \tag{D.35}$$

where

A_{CT} is the cross-sectional area of the load bearing member excluding the depth where the temperature exceeds 500 °C (mm²);

$\bar{\sigma}_c$ is the standard stress of the load bearing member at room temperature (N/mm²);

provided that the depth over 500 °C shall not exceed 2× covering thickness of reinforcing bars.

b) Regarding bending strength in fire, a beam whose compressed part is exposed to fire satisfies condition 1) [see Formula (D.36)] and a beam whose tensile part is exposed to fire shall satisfy condition 2) [see Formula (D.39)], respectively. However, a structural frame whose stresses may be re-distributed can be verified based on the re-distributed stresses.

1) A beam whose compressed side is exposed to fire

$$M_e(T) > M_D \tag{D.36}$$

where

$M_e(T)$ is the bending strength at compressed part of the load bearing member in fire (Nmm);

M_D is the bending moment at compressed part of the member due to long time design loading (Nmm);

$M_e(T)$ is calculated by Formula (D.37):

$$M_e(T) = a_t \cdot f_t(T) \cdot j_e \tag{D.37}$$

where

a_t is the cross-sectional area of tensile reinforcing bars (mm^2);

$f_t(T)$ is the allowable stress of tensile reinforcing bars in fire (N/mm^2);

j_e is the effective depth of the load bearing member (mm);

and j_e is calculated by Formula (D.38):

$$j_e = \frac{7}{8}(D - d_c) \tag{D.38}$$

where

D is the depth of the load bearing member (mm);

d_c is the depth of the part of the load bearing member where temperature exceeds 500 °C (mm);

provided that the depth over 500 °C is less than 2× the covering thickness of reinforcing bars.

2) A beam whose tensile side is exposed to fire

$$M_c(T) > M_D \tag{D.39}$$

where

$M_c(T)$ is the bending strength at the tensile part of the load bearing member in fire (Nmm);

M_D is the bending moment due to long time design loading (Nmm).

In Formula (D.39), $M_c(T)$ is calculated by Formula (D.40):

$$M_c(T) = a_t \cdot f_t(T) \cdot j_e \tag{D.40}$$

where

a_t is the cross-sectional area of the tensile reinforcing bars (mm^2);

$f_t(T)$ is the allowable stress of the tensile reinforcing bars in fire (N/mm^2);

j_e is the effective depth of the load bearing member (mm);

and j_e is calculated by Formula (D.41):

$$j_e = \frac{7}{8} d \tag{D.41}$$

where

d is the distance from the upper surface of the load bearing member to the centre of the tensile reinforcing bars (mm), provided that the yield strength of the load bearing member $f_t(T)$ in the above 1) and 2) shall be estimated by the following.

— The $\sigma_y(T)$ of generally used reinforcing bars, or others whose mechanical properties at high temperature are equal or superior to these, can be estimated by Formula (D.42).

$$f_t(T) = \left\{ \begin{array}{|ll|} \overline{f_t} & (T \le T_1) \\ \overline{f_t} \dfrac{T_2 - T}{T_2 - T_1} & (T_1 < T \le T_2) \\ 0 & (T_2 < T) \end{array} \right\} \tag{D.42}$$

where

$\overline{f_t}$ is the standard strength of reinforcing bars at room temperature (N/mm^2);

T is the temperature of reinforcing bars in fire (°C);

T_1 is the temperature at which the strength of reinforcing bars begin to decrease (= 325) (°C);

T_2 is the temperature at which the strength of reinforcing bars becomes zero (= 700) (°C).

— Yield strength of such a reinforcing bar whose product lot can be identified and whose properties at high temperatures are available can be estimated by multiplying 0,9 to the strength at 1 % strain in its stress-strain curve.

NOTE Generally, in the design of reinforced concrete structures, reinforcing bars are counted only for bearing tensile stress and ignored for the compressive stress. On the other hand, concrete is counted only for bearing compressive stress but ignored for tensile stress.

Like steel members, the yield strength of reinforcing bars is deteriorated by temperature rise in fire. The strength of concrete also decreases due to the deterioration of material quality by exposure to heat. Though its strength as a function of temperatures is not as clear as that of the steel, it is assumed here for simplicity that the strength at room temperature is maintained at constant up to 500 °C but becomes zero over 500 °C. Therefore, load bearing members for compressive load such as columns are required to be capable to bear long time design loading only by the residual sound part excluding the portion over 500 °C, of which the compressive strength is disregarded.

On the other hand, beams bear loading by bending stress. In some cases, the lower side, and in other cases, the upper side, of a beam is in the tensile side at its end or central part. Needless to say, when the lower side is in tensile, the opposite upper side is in compression, and conversely when the upper side is in tensile side, the lower part is in compression.

Considering a reinforced concrete beam heated in tensile side, its load bearing ability through the bending stress declines due to the temperature rise of reinforcing bars in tensile side. Though the concrete deteriorates in the heated part too, the load bearing ability of a beam in fire is evaluated only based on the strength of reinforcing bars, because tensile stress of concrete is disregarded in design of concrete beam. If a beam is heated at compressive side, the compressive strength of concrete is degraded. So the strength at temperatures over 500 °C is regarded here as zero. And since the temperature rise can reach the tensile side, the decrease of strength of reinforcing bars at tensile side is also taken into consideration.

D.3.2.4 Struct.Stability-(C.3)

In case of wooden structure, every load bearing member satisfies both of the following conditions:

a) Axial strength in fire satisfies both of the following conditions.

1) Axial compressive strength

$$P_C(T) > P_D \tag{D.43}$$

where

$P_C(T)$ is the axial compressive strength of the load bearing wooden member in fire (N);

P_D is the axial force due to long time design loading (N).

In Formula (D.43), $P_C(T)$ is calculated by Formula (D.44):

$$P_C(T) > A_C \cdot \bar{\sigma}_y \tag{D.44}$$

where

A_C is the cross-sectional area of the load bearing wooden member excluding charred part (mm^2);

$\bar{\sigma}_y$ is the allowable compressive stress of the load bearing wooden member at room temperature (N/mm^2).

2) Axial buckling strength in fire

$$P_B(T) > P_D \tag{D.45}$$

where

$P_B(T)$ is the buckling strength of the load bearing wooden member in fire (N);

P_D is the effective buckling force due to long time design loading (N).

In Formula (D.45), $P_B(T)$ is calculated by Formula (D.46):

$$P_B(T) = A_C \cdot \sigma_{cr} \tag{D.46}$$

where

A_C is the cross-sectional area of the load bearing wooden member excluding charred part (mm^2);

σ_{cr} is the buckling stress of the load bearing wooden member in fire (N/mm^2);

and σ_{cr} is calculated by Formula (D.47):

$$\sigma_{cr}(T)=\begin{cases}\left(1-0{,}4\left(\frac{\lambda}{\Lambda}\right)^2\right)\overline{\sigma}_y & (\Lambda<\lambda)\\ \dfrac{0{,}6\overline{\sigma}_y}{\left(\frac{\lambda}{\Lambda}\right)^2} & \end{cases} \tag{D.47}$$

where

λ is the slender ratio (= buckling length/radius of gyration) (-);

$\overline{\sigma}_y$ is the yield compressive stress of the load bearing member at room temperature (N/mm²);

Λ is the limit slender ratio $(=\sqrt{\pi\overline{E}/0{,}6\overline{\sigma}_y})$ (-);

$\overline{E}$ is the Young's modulus of the load bearing wooden member at room temperature (N/mm²).

b) Bending strength in fire

$$M(T)>M_D \tag{D.48}$$

where

$M(T)$ is the bending strength of the load bearing wooden member in fire (N/mm);

M_D is the bending moment due to long time design loading (N/mm).

In Formula (D.48), *M(T)* is calculated by Formula (D.49):

$$M(T)=Z_x\cdot\overline{\sigma}_y \tag{D.49}$$

where

Z_x is the section modulus of the load bearing wooden member excluding charred part (mm³);

$\overline{\sigma}_y$ is the allowable bending stress of the load bearing wooden member at room temperature (N/mm²).

NOTE This criterion is to ensure that the residual strength of a wooden structural member is yet larger than the force due to its long time loading even though its cross-sectional area is reduced by fire. Though there are many unknown aspects on behaviour of wooden structure, it is considered here that the wooden structure can be treated basically in the same way as steel structure. In addition, in view of fire resistance of wooden structures, joint parts tend to be most vulnerable, so it needs a particular protection measure in its design.

D.3.3 Criteria for prevention of hazard to neighbourhood due to collapse

A building that complies with whichever of the following criteria is deemed to be at acceptable level with respect to prevention of hazard to the neighbourhood due to collapse thereof.

D.3.3.1 Hazard.Collapse-(D.1)

Every part of the building satisfies the following condition:

$$H<D \tag{D.50}$$

where

H is the height of the part of the building from the site level (m);

D is the minimum horizontal distance from the concerning part to the site boundary (m).

NOTE This is a criterion to verify the compliance with this requirement in a simple manner. It is not easy to predict collapsing behaviour of a building. However, if a building would fall on within its lot if ever it would overturn, the trouble to the neighbour would be minimal. Actually, it must be very rare that a building overturns, so this criterion is significantly conservative.

D.3.3.2 Hazard.Collapse-(D.2)

Dimensions of the building satisfy both of the following conditions:

a) Geometric condition not to overturn even if bearing members collapse

$$\frac{h}{\sqrt{D^2 - h^2}} > \frac{D}{H - h} \tag{D.51}$$

where

H is the height of the building (m);

D is the length of the sorter side of the building (m);

h is the maximum of the floor heights of the building (m).

b) Protrude out length of whatever part of the building when bearing members collapse

$$s < d \tag{D.52}$$

where

s is the horizontal displacement of the part of building due to leaning (m);

d is the minimum horizontal distance from the part to the site boundary (m).

NOTE This is also a criterion for convenience in verifying the compliance. If floor area of a building is large relative to height, it can lean but never overturns even if its columns or bearing walls collapse. Most disadvantageous scenario regarding the collapse of a building is that all the columns at one side on the ground level collapse all together to slant the building. The above criterion a) give the condition that gravity centre of a slant building stays within the range of the floor area. It is derived only based on static configuration, so dynamic behaviour at the time of leaning is ignored. However, columns on the other side may work to hold back the slant, so it is thought to be a reasonable criterion for the rough judging.

In addition, if a building leans, a part of a building can shift toward the neighbouring site. The condition b) is to prohibit any part of the building to stick out into the third party's property.

D.3.3.3 Hazard.Collapse-(E)

From the particular conditions of the building concerned, it is deemed that the building would not fall down onto the neighbouring site by fire.

NOTE Even if a building does not meet the above-mentioned two criteria, it is not a very difficult situation for the building since it only has to be fire resistive. However, there must be many cases that a building can be judged not to overturn to neighbouring sites by fire if its conditions of shape or structure are closely examined. It is not easy to establish a common standard considering such a variety of particular conditions, so it will be appropriate to resort to expert discretion.

D.4 Prevention of fire spread

The following criteria apply to the verification of compliance with:

a) **FNR I-4.1.1** (A building shall not cause fire spread to buildings on others' property in the event a fire breaks out therein) in **I-4.1 Prevention of fire spread to the third party's building**;

b) **FNR I-4.3.1** (A building that is divisionally owned by multiple natural or juridical persons shall not cause fire spread to parts of the building owned by others, in whichever part in the building a fire may occur) in **I-4.3 Prevention of fire spread to the third party's space**;

c) **FNR II-1.1.1** (A building in a fire prevention district shall not cause fire spread to other buildings in the event of fire, whether the fire may be originated therein or caused by fire spread from an urban fire) in **II-1.1 Breaking fire spread in urban districts**;

d) **FNR II-1.1.2** (A building in a fire prevention district shall not be susceptible to fire spread from adjacent buildings on fire) in **II-1.2 Protecting trunk roads for emergency management**;

e) **FNR II-2.1.1** (Any building in a semi-fire prevention district shall not cause fire spread easily to other buildings in the event of fire) and **FNR II-2.1.2** (A building in a semi-fire prevention district shall not be susceptible to fire spread from other buildings) in **II-2.1 Retardation of urban fire spread**.

D.4.1 Terms and definitions

D.4.1.1

adjacent building

building in neighbour owned by others or used by tenants

D.4.1.2

adjacent space

space that is separated from the room of fire origin by walls, floor slabs, or free spaces

D.4.2 Criteria for prevention of causing fire spread to neighbour buildings by radiation

A building that complies with either of the following criteria during the prescribed time of fire is deemed to be acceptable with respect to safety performance for preventing to cause fire spread to neighbouring buildings due to fire radiation.

D.4.2.1 Firespread.to.Bldg.by.Radiation-(P.)

The radiation from the building satisfies both of the following conditions:

a) Radiant heat flux to any point at 3 m in recess into adjacent sites from the property line satisfies

$$\int_0^{t_D} q_3''^2 dt \leq 2{,}0 \times 10^3 \qquad \text{(D.53)}$$

where

q_3'' is the radiant heat flux to any point on the vertical surface envisaged on lines that is 3 m in recess into adjacent sites from the property line (kW/m²);

t_D is the prescribed duration of fire (min).

b) Radiant heat flux to any point at 0,5 m in recess into adjacent sites from the property line satisfies

$$\int_0^{t_D} q''^2_{0,5} dt \leq 3{,}2 \times 10^4 \tag{D.54}$$

where

$q''_{0,5}$ is the radiant heat flux to any point on the vertical surface envisaged on lines that is 0,5 m in recess into adjacent sites from the property line (kW/m^2);

t_D is the prescribed duration of fire (min).

Nonetheless, none of the above conditions a) and b) has to be satisfied for property line between roads, parks, riverbeds, agricultural fields, forests or others where no buildings are expected to be constructed.

NOTE An exterior wall of a house in a congested urban area is required to be semi-fire resistive construction if the wall is within 3 m from the property boundary by the Building Standards Law, and only a fire-resistant wall is allowed within 0,5 m from the property boundary. The semi-fire resistive construction had been assessed for a long time until recently by fire tests subjected to the second-class standard temperature-time curve, which was developed based on the fire tests of conventional wooden houses. The temperature of this curve quickly reaches 840 °C at peak but its duration over 800 °C is only about 5 min.

The critical radiant heat flux for ignition of wood is 10 kW/m^2 or more, and those of usual window glass breaking and ignition of curtains inside of window are considered to be about the same order. Generally, fire temperature and duration depend on conditions of fire room and fire load, which differ intensity and duration of incident heat flux to neighbouring buildings from one to another. Though it is not easy to establish the equivalency of the effects to building elements exposed to such different heat fluxes, it is regarded that the following relation approximately holds:

$$q''^2 t = const. \tag{n1}$$

where q'' is the incident heat flux and t is the duration of heating.

Using experimental data from ISO cone heater ignitability tests of wood, Formula (n1) is approximated as

$$q''^2 t = 2{,}000 \tag{n2}$$

where the time t is in minute. This is adopted as the criterion of the radiant heat flux to a surface at 3 m in recess from the site boundary.

For the criterion of the radiant heat flux to the surface at 0,5 m in recess from the site boundary, results of fire test for rating second class fire resistive construction are applied. Since temperature of 800 °C is roughly equivalent to heat flux of 80 kW/m^2:

$$q''^2 t = 80^2 \times 5 = 32{,}000 \tag{n3}$$

A direct effect of this standard is that window size is limited according to the distance from property boundary. In addition, it also implies that exterior walls must endure the fire for the prescribed duration. If an exterior wall is damaged by fire to enlarge openings, it will be more difficult to satisfy this criterion.

D.4.2.2 Firespread.to.Bldg.by.Radiation-(C.)

The radiation from the building satisfies both of the following conditions:

a) Radiant heat flux to any point at 3 m in recess into adjacent sites from the property line satisfies:

$$q''_3 \leq 10 \tag{D.55}$$

