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First edition

Fire safety engineering — Performance of structures in fire —

Part 5: Example of a timber building in Canada

PROOF/ÉPREUVE

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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

A list of all parts in the ISO 24679 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

This document provides an example of the application of ISO 24679-1. The procedure described this document is intended to follow the principles outlined in ISO 24679-1. It therefore preserves the numbering of subclauses in ISO 24679-1, omitting numbered subclauses for which there is no text or information relevant to this example.

The example provided in this document is intended to illustrate the implementation of the steps of fire resistance assessment, as defined in ISO 24679-1, and to demonstrate how this ISO 24679-1 can be applied to different building regulatory systems. It is not intended to demonstrate full conformance of a performance-based fire engineering design seeking approval. Therefore, only a limited number of fire design scenarios and structural assessments are presented.

Fire safety engineering — Performance of structures in fire —

Part 5: Example of a timber building in Canada

1 Scope

This document provides a fire engineering application relative to the fire resistance assessment of a multi-storey timber building according to the methodology given in ISO 24679-1. In an attempt to facilitate the understanding of the design process presented herein, this document follows the same step-by-step procedure as that given in ISO 24679-1.

The fire safety engineering approach is applied to a multi-storey timber building with respect to fire resistance and considers specific design fire scenarios, which impact the fire resistance of structural members.

A component-level (member analysis) approach to fire performance analysis is adopted in this worked example. Such an approach generally provides a more conservative design than a system-level (global structural) analysis or an analysis of parts of the structure where interaction between components can be assessed. An advantage of the component-level approach is that calculations can be done with the use of simple analytical models or spreadsheets. Advanced modelling using computational fluid dynamics is presented to replicate an actual office cubicle fire scenario and for assessing timber contribution to fire growth, intensity and duration, if any. The thermo-structural behaviour of the timber elements is assessed through advanced modelling using the finite element method.

The fire design scenarios chosen in this document are only used for the evaluation of the structural fire resistance. They are not applicable for assessing, for example, smoke production, tenability conditions or other life safety conditions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943, *Fire safety — Vocabulary*

ISO 23932-1, *Fire safety engineering — General principles — Part 1: General*

ISO 24679-1, *Fire safety engineering — Performance of structures in fire — Part 1: General*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943, ISO 23932-1 and ISO 24679-1 apply.

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

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

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

4 Design strategy for fire safety of structures

4.1 General design process for fire safety of structures

The built environment used in this example is a medium-rise office building. To accommodate tenant office functions, the building is separated into multiple compartments by floors and walls. Given that an office space typically consists of several office workstation or cubicles, it is likely that a fire will spread to neighbouring elements and eventually across the entire floor surface. As such, a fully-developed compartment fire is expected in each office suite of the building.

The structural elements are of glue-laminated timber beams and columns, where portions of the primary structural timber elements are left exposed for aesthetic purposes. The secondary structural elements are protected against fire using fire-resistance rated gypsum boards.

The fire development was studied using computational fluid dynamics (CFD) modelling, with specific considerations for capturing the potential fuel contribution from the structural timber elements. Time-temperature curves were produced, as well as relevant key events during the fire development (growth, flashover conditions, consumed fuel load, etc.).

Simplified and advanced models have been used to define the thermal actions applied to the timber elements. The thermomechanical behaviour of the main structure of the office building, based on simplified and advanced methods, is carried out as a function of the actual thermal actions defined previously.

4.2 Practical design process for fire safety of structures

Refer to ISO 24679-1 for more information about the various steps and parameters to be considered when assessing the behaviour of structures subjected to fire exposure.

5 Quantification of the performance of structures in fire

5.1 Step 1: Scope of the project for fire safety of structures

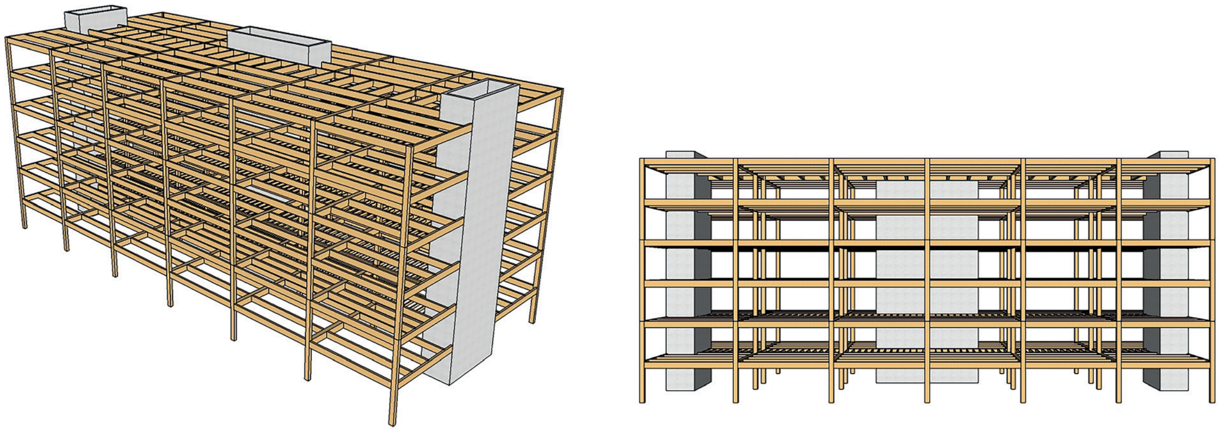
5.1.1 Built-environment characteristics

The built environment consists of a 6-storey office building constructed with a timber structure. The floor area of each storey is approximately 960 m^2 for a total floor area of 5 760 m^2. Access to each floor is provided by two reinforced concrete exit stairs located at each end of a public corridor. An elevator shaft made of reinforced concrete is also provided and is located near the centre of the floor area. Figure 1 illustrates the structural framing of the building. Every floor has a clear interior floor/ceiling height of 3,0 m. These floor assemblies are required to form a fire separation with a fire-resistance rating not less than 1 hour. Load-bearing walls and columns are required to provide a fire-resistance rating not less than that required for the supported elements and assemblies.

According to the applicable national prescriptive provisions,[4] a 6-storey office building using a timber structural system is required to be fully protected by an automatic sprinkler system conforming to NFPA 13.[5] It is also required to have fire detection and fire alarm systems.

The primary and secondary structural elements consist of glued-laminated timber beams and columns of the 20f-E and 12c-E Spruce-Pine (SP) stress grades.[6],[7] The floor structure is made of traditional visually-graded solid-sawn double tongue-and-groove plank decking, of the Spruce-Pine-Fir (SPF) No.2 visually-graded lumber grade.[8] The plank decking is laid perpendicularly to the supporting secondary beams, which are spaced every 2 m (centre to centre). All timber elements conform to the national lumber grading rules.[9] The structural engineering design, for ambient/normal conditions, conforms to the relevant design standard.[8]

Concealed connections between the primary and secondary structural elements are used, in which metallic components such as self-tapping screws driven at 45° are fully embedded into the wood members to limit potential thermo-mechanical degradation from fire exposure. Figure 2 illustrates the floor structure and location of load-bearing elements. Figure 3 illustrates the connections and their embedment into the load-bearing elements. The characteristics of the load-bearing elements assumed in this example are given in Table 1. The dimensions of the main elements are greater than required for structural purposes due to the embedment of the load-bearing elements; they need to be able to provide sufficient bearing lengths to the embedded main and secondary beams. The chosen elements considered for demonstrating the procedure of ISO 24679-1 are a main beam, B1, located above the fire source and its supporting column, C2, towards the exterior wall.



a) Isometric view **b) Front view**

Figure 1 — Structural frame

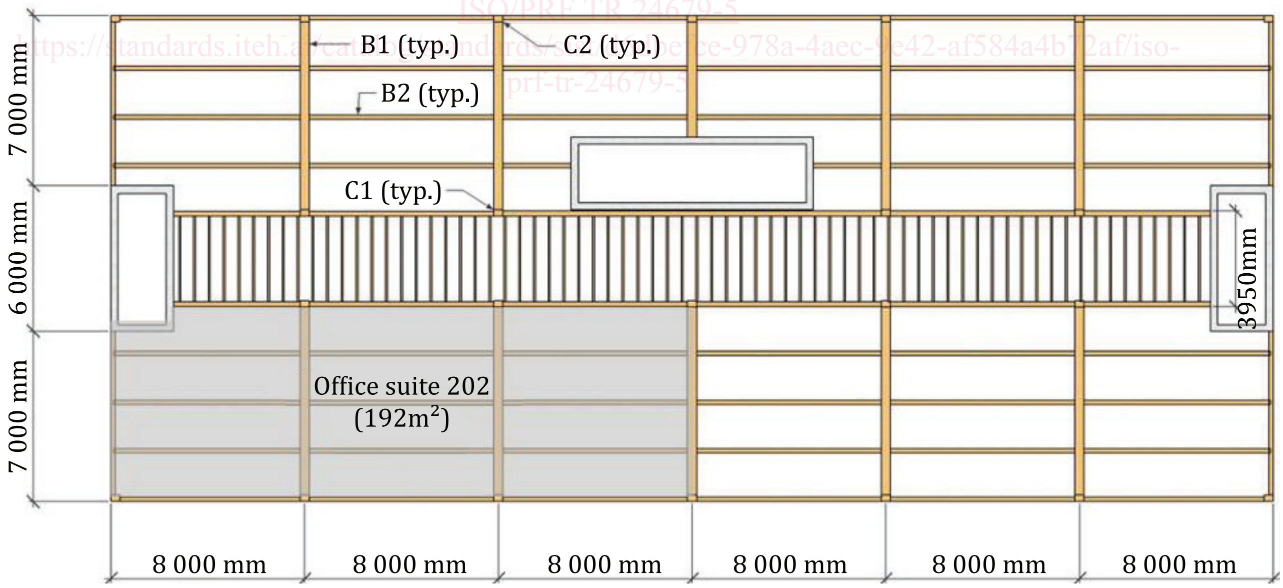
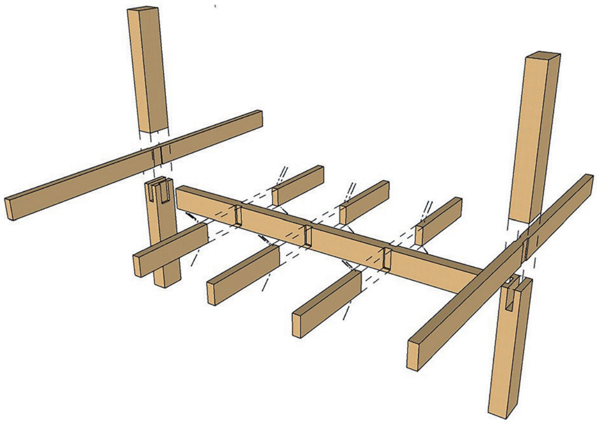
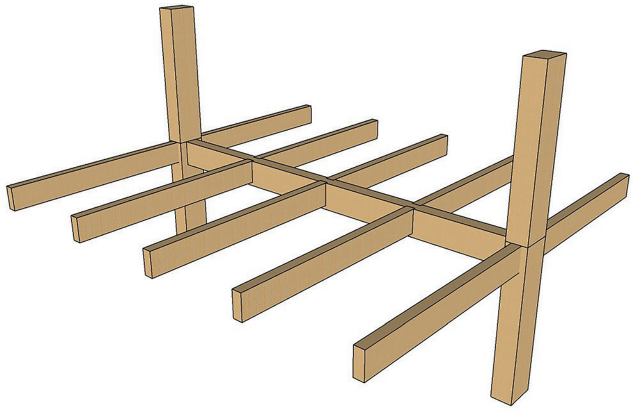


Figure 2 — Typical floor structural configuration



a) "Before" frame assembly



b) "After" frame assembly

Figure 3 — Detailing of the connections

Table 1 — Load-bearing elements characteristics — Preliminary design (ambient conditions)

Element	Type	Dimensions mm	Gypsum board
B1	Glulam 20f-E	265 × 532[a]	None
B2	Glulam 20f-E	175 × 456[b]	None
C1	Glulam 12c-E	418 × 365	None
C2	Glulam 12c-E	342 × 365	None
Decking	S-P-F No.2	89 × 133	1 × 16 mm Type X
Partitions	Wood studs	38 × 89[c]	2 × 13 mm Type X

a At 8 000 mm centre-to-centre (c/c).

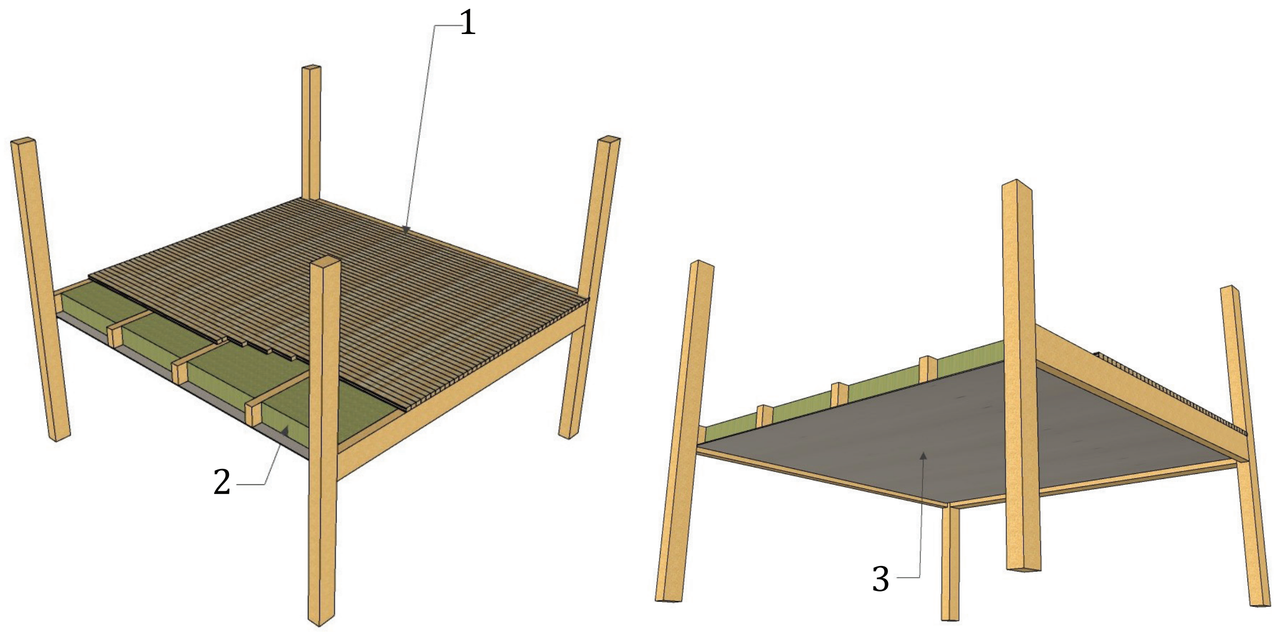
b At 2 000 mm c/c.

c At 600 mm c/c.

The dropped-ceiling assembly forms a cavity filled with non-combustible insulation for providing the required sound transmission class (Figure 4). The exposed ceiling consists of a single layer of 16 mm fire-rated gypsum board (e.g. Type X) fastened to the secondary beams in conformance with national specifications.[10],[11] With this specific configuration, a limited portion of the primary beams and columns are left exposed and can thus contribute to fire growth and severity.

Partitions made from wood stud walls are used to separate the office suites and the public corridor within the floor area. They are constructed using 38 mm × 89 mm wood studs spaced at 600 mm. Two (2) layers of 13 mm Type X gypsum board (i.e. fire-resistance rated gypsum boards) are installed on both sides of the studs, providing a 1 hour fire-resistance rating when tested by a standard fire-resistance test.[12] The inside cavities of the stud walls are filled with 89-mm thick non-combustible insulation in order to provide both the prescribed fire-resistance rating and the sound transmission class.

According to the applicable national prescriptive provisions, these partitions are not required to be constructed as a fire separation and are not required to provide a fire-resistance rating because the building is entirely protected by automatic sprinklers and the maximum travel distance from any part of the floor area to an exit is not more than 45 m. Assessment of the fire performance of the partitions is therefore beyond the scope of this document.



a) Isometric view **b) View of the ceiling**

Key

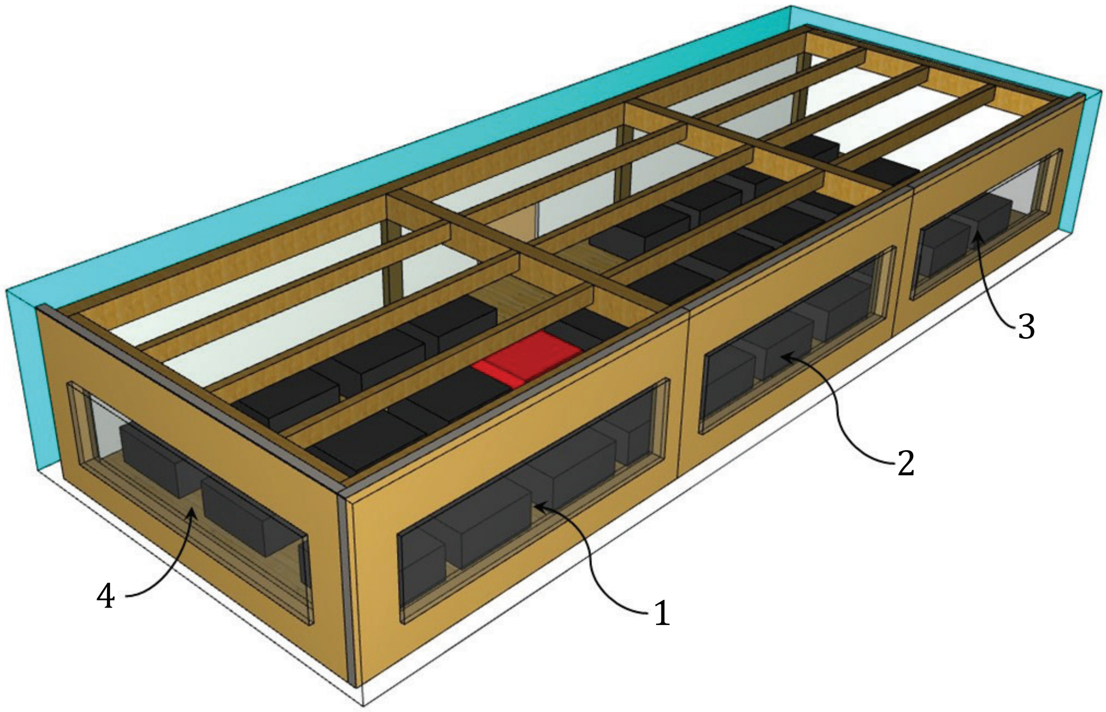
1 89 mm × 133 mm plank decking with double tongue-and-groove

2 concealed spaces filled with non-combustible insulation

3 16 mm type X gypsum board

Figure 4 — Floor assembly

For the purpose of this document, the office suite to be analysed is located on the second floor and represents the compartment of fire origin. It is a 192 m^2 open-space office suite in which cubicles with computers, desks, chairs and filing cabinets are uniformly distributed across the floor area (Figure 5).



Key

1 window 1

2 window 2

3 window 3

4 window 4

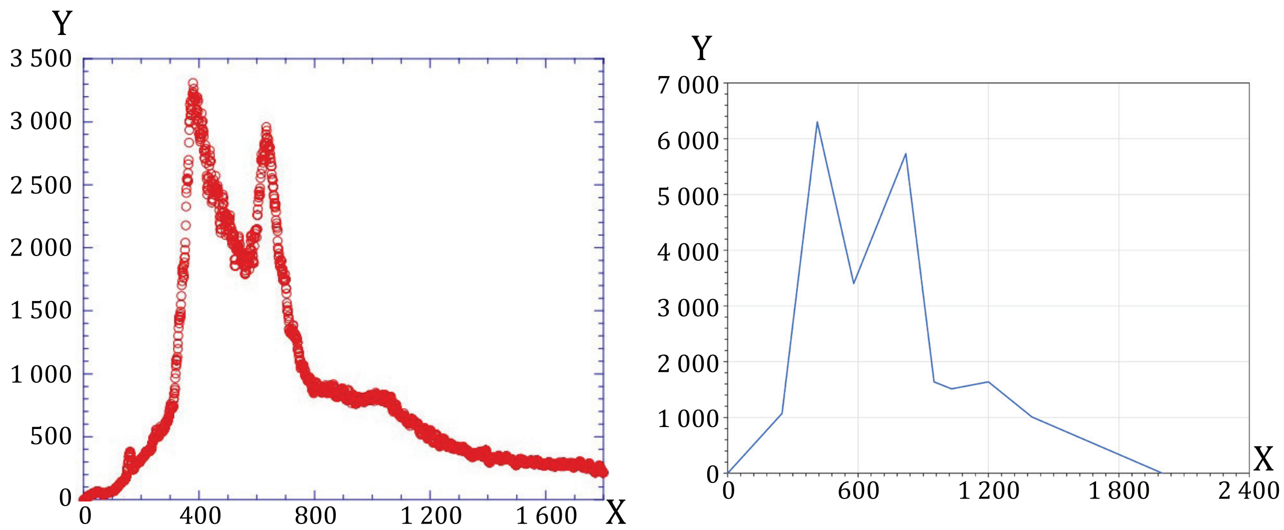
Figure 5 — Isometric view of office suite (compartment of fire origin)

5.1.2 Fuel loads

Fire loads consist of the total energy content of combustible materials in a building, a space or an area including furnishing and contents within a compartment (i.e. moveable fire load) and combustible materials used as structural elements, interior finishes or installed in concealed spaces (i.e. fixed fire load). The office suite where the fire is assumed to start consists of an open-space configuration with 28 cubicles and an engineered hardwood flooring of 13 mm in thickness, see Figure 5. Each cubicle measures 1,8 m × 1,8 m (3,24 m^2). The typical combustible materials found in cubicles are paper, wood, plastic and textiles.

An average moveable fuel load density of 420 MJ/m^2 is typically assigned for an office space.[13-15] However, it is typically recommended to use the 95th percentile value for fire design purposes. A 95th percentile value of 760 MJ/m^2 is suggested for offices in Reference [14]. Zalok[16] found 95th percentile fuel loads of 8 822 MJ and 15 666 MJ for small floor area cubicle offices (11 m^2) and large floor area enclosed offices (25 m^2), respectively. It was also reported that offices with large floor area result in lower fire load densities (626 MJ/m^2), when compared to that of smaller floor areas (802 MJ/m^2). Given the large floor area of this example (192 m^2), a value of 735 MJ/m^2 is deemed appropriate, and consistent with that provided in References [14-16].

The National Institute of Standards and Technology (NIST)[17] evaluated the heat release rate (HRR) of a single workstation covering a floor area of 1,93 m × 1,63 m (3,15 m^2) as well as multiple workstations (4 workstations assembled in similar manner as the single workstation). A total fuel load mass of 273,2 kg was measured for the single workstation. Assuming an effective heat of combustion of 18 MJ/kg, a total energy of 4 917 MJ is estimated for a single workstation. The HRR obtained in the NIST study is illustrated in Figure 6 a). The workstation HRR development curve used for performing the computational fluid dynamics (CFD) modelling in Fire Dynamics Simulator (FDS) version 6.7 is shown in Figure 6 b). The workstation HRR development curve is further explained below.



a) HRR, as presented in Reference [17]

b) HRR implemented in FDS

Key

X time (s)

Y heat release rate (kW)

Figure 6 — Heat release rate of a single workstation

For the purpose of this document, the moveable fuel load energy density, *FLED,* is comprised of a total of 28 cubicles uniformly distributed along the 192 m^2 floor area, $FLED_{cubicles}$, and the hardwood flooring, $FLED_{flooring}$. In an attempt to replicate a uniform fuel load density of 735 MJ/m^2, each cubicle has been set to 4 082 MJ. The cubicle individual HRR development growth has been kept similar to that shown in Figure 6 b). The 13-mm thick hardwood flooring density is assumed to be 600 kg/m^3 with an effective heat of combustion of 18 MJ/kg. A resulting moveable FLED value of 735 MJ/m^2 is obtained using Formula (1).

$$FLED = FLED_{\text{flooring}} + FLED_{\text{cubicles}} \tag{1}$$

The total fuel mass, m_{Total}, can be estimated from the fire load energy density (*FLED*), the total floor area, A_f, of 192 m^2, and an effective heat of combustion, H_{eff}, of 18 MJ/kg (wood equivalent), using Formula (2):

$$m_{\text{Total}} = \frac{A_{\text{f}} \cdot FLED}{H_{\text{eff}}} \tag{2}$$

The total fuel mass of 7 840 kg is required for determining the design fire curve, as presented in 5.4.2.

The moveable fuel load density calculated in Formula (2) does not include the potential contribution from the timber structural elements. The latter will be explicitly considered when performing CFD modelling, as described in 5.4.3.3.

5.1.3 Mechanical actions

According to the applicable national design requirements,[18] the load combination, P, for a rare/accidental event such as a fire is taken as shown in Formula (3):

$$P = 1{,}0\,D + (\alpha L + 0{,}25\,S) \qquad (3)$$

where

D is the permanent load;

α is taken as 1,0 for storage areas, equipment areas and service rooms, or 0,5 for other occupancies;

L is the live load due to occupancy;

S is the snow load.

For an office space, a minimum live load of 2,4 kPa is prescribed in the national design provisions.[18]

Given that the low probability that all floors of a multi-storey building would be structurally loaded to its full live load simultaneously, a live load reduction factor can be used based on the tributary area supported by columns. For a column supporting a tributary area greater than 20 m^2 and for this type of building occupancy, as with the case of column C2 (32 m^2) in this office building, the applicable national design requirements[18] allow the applied live load to be multiplied by the value shown in Formula (4):

$$0{,}3 + \sqrt{\frac{9{,}8}{B}} \qquad (4)$$

where B is the tributary area of the supporting column (m^2).

While post-earthquake fires can occur, fires and earthquakes are both considered as rare events and thus deemed not to occur at the same time. Therefore, horizontal actions due to wind and seismic forces are typically not considered for structural fire-resistance, unless specifically stipulated in the applicable building code.

5.2 Step 2: Identifying objectives, functional requirements and performance criteria for fire safety of structures

5.2.1 Objectives and functional requirements for fire safety of structures

Conducting a rational fire safety design of structures requires the establishment of fire safety objectives and functional requirements. With respect to fire resistance of structures, the qualitative objectives typically relate to the fire safety of occupants as well as the fire protection of the building.

From the applicable national building code, the objective for fire safety is to limit the probability that, as a result of the design, construction or demolition of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire caused by:

a) a fire impacting areas beyond its point of origin; and

b) collapse of physical elements due to a fire.

Similarly, the objective for fire protection of the building is to limit the probability that, as a result of the design, construction or demolition of the building, the building or adjacent buildings will be exposed to an unacceptable risk of damage due to fire caused by:

a) a fire impacting areas beyond its point of origin; and

b) collapse of physical elements due to a fire.

In addition to these objectives, functional requirements are typically provided and linked to the objectives to clarify the intent. With respect to structural fire resistance, the functional requirements (also called functional statements in the applicable national building code) are to retard the effects of a fire on areas beyond its point of origin and the retard failure or collapse due to effects of the fire. The pairing of the functional statements and the objectives results in the following statements of intent:

a) to limit the probability that materials, assemblies or structural members will have insufficient resistance to the spread of fire, which could lead to harm to persons;

b) to limit the probability that materials, assemblies or structural members will have insufficient resistance to fire, which could lead to their failure or collapse, which could lead to harm to persons;

c) to limit the probability that materials, assemblies or structural members will have insufficient resistance to the spread of fire, which could lead to damage to the building; and

d) to limit the probability that materials, assemblies or structural members will have insufficient resistance to fire, which could lead to their failure or collapse, which could lead to damage to the building.

In satisfying the functional requirements, it is essential to take into consideration the existence of active and passive fire control systems and their effectiveness.

5.2.2 Performance criteria for fire safety of structures

Performance criteria are used to determine whether the objectives and functional requirements for the fire safety of structures have been satisfied.

It is stipulated in a national design standard that structures are to be designed to prevent collapse of the structure itself and to exhibit adequate load-bearing capacity and capability to maintain structural integrity for a sufficient time.[19] According to Reference [19], ensuring structural integrity for complete burn out of the moveable fire load of any fire compartment is only required for tall (high) buildings. In the context of this worked example, a 6-storey office building does not classify as a tall (high) building, as defined in the applicable national prescriptive provisions, and is therefore not required to achieve complete burnout of the moveable fuel content.

Therefore, the performance criterion used in this worked example is taken as the time at which the impinging heat flux on the exposed surfaces of the timber elements reduces below 5 kW/m^2. Below this threshold, it is assumed that the moveable fuel load will most likely be consumed and that smouldering timber elements will stop charring and no longer contribute to the fire heat release rate.[20] A reduction in the net emitted energy to the exposed timber surfaces results in a reduction in the mass production of volatiles, which will result in extinction if such reduction is sufficient (i.e. flaming will cease at the timber surfaces). Moreover, auto-extinction of flaming combustion of Spruce with a density of 425 kg/m^3 has been found to occur if the timber mass loss rate reduces below 3,93 $g/m^2 \cdot s$ and the heat flux is less than 43,6 kW/m^2.[21,22] This threshold has been found to be dependent upon the timber species, but not the density[22].

The objectives and functional requirements are deemed to be satisfied when the load-bearing function, and separating function where appropriate, remain fulfilled until the criteria of heat flux and mass loss rate are reached. The proposed performance criteria are considered as reasonable assumptions based on scientific knowledge available at the time of writing this document. Other performance criteria could be used as new evidence is made available, provided they are supported by technical test data.

5.2.2.1 Performance criteria to limit fire spread (compartmentation)

The compartmentation of a built environment in order to prevent or to limit the fire spread can be achieved by load-bearing elements such as walls and floors, or by non-load-bearing elements, such as partition walls, doors, windows, etc. These elements need to satisfy functional requirements related to integrity, insulation and mechanical resistance or stability.