Chapter 5 Common Acceptance Criteria

5.1 Assurance of Life Safety

5.1.1 Terminology

5.1.1.1 Indoor space
Space inside of the envelop of a building

5.1.1.2 Outdoor space
Space outside of the envelop of a building

5.1.1.3 Evacuation space
Space used as an escape route or a refuge

5.1.1.4 Evacuation period
Period during which evacuees stay in a space on an evacuation route or in a refuge

5.1.1.5 Fire room side space
A space located at the fire room side of an opening or a partition wall on a route of smoke propagation

5.1.1.6 Evacuation side space
An space located at the evacuation route side of an opening or a partition wall on a route of smoke propagation

5.1.2 Acceptance Criteria for Safety of Evacuees from Smoke in Building

An indoor space of a building that satisfies whichever of the following criteria: 5.1.2.1-5.1.2.4 during the prescribed time is deemed to be at acceptable level with regard to the safety of occupants from smoke.

5.1.2.1 Evac.Smoke.Indoor-(P.)
The smoke to which any of evacuees is exposed in the space satisfies:
\[
\int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1.0 \times 10^4 \tag{5.1.2.1-1}
\]
where \( \Delta T \) : Temperature rise of the smoke to which the evacuee is exposed [K]
\( t_1 \) : Time at which the evacuee begins to be exposed to the smoke [sec.]
\( t_2 \) : Time at which the evacuee ceases to be exposed to a smoke [sec.]

In the above formula, either of the following conditions (a) or (b) can be used to judge if an evacuee in the space is exposed to smoke:

(a). Temperature of smoke
\[
\Delta T > 0 \tag{5.1.2.1-2}
\]
where $\Delta T$: Temperature rise of the smoke in the space [K]

(b) Height of smoke layer

$$S < 1.6 + 0.1H$$ (5.1.2.1-3)

where $S$: Height of the smoke layer interface from the floor of the evacuee [m]

$H$: Average ceiling height of the space from the floor of the evacuee [m]

5.1.2.2 Evac.Smoke.Indoor-(C.1)

The smoke to which any of evacuees is exposed in the space satisfies:

$$\left( \Delta T_{\text{max}} \right)^2 \left( t_2 - t_1 \right) < 1.0 \times 10^4$$ (5.1.2.2-1)

where $\Delta T_{\text{max}}$: Maximum temperature rise of the smoke to which the evacuee is exposed [K]

$t_1$: Time at which the evacuee begins to be exposed to the smoke [sec.]

$t_2$: Time at which the evacuee ceases to be exposed to a smoke [sec.]

In the above formula, either of the following conditions (a) or (b) can be used to judge if an evacuee in the space is exposed to smoke:

(a) Temperature of smoke

$$\Delta T > 0$$ (5.1.2.2-2)

where $\Delta T$: Temperature rise of the smoke in the space [K]

(b) Height of smoke layer

$$S < 1.6 + 0.1H$$ (5.1.2.2-3)

where $S$: Height of the smoke layer interface from the floor of the evacuee [m]

$H$: Average ceiling height of the space from the floor of the evacuee [m]

5.1.2.3 Evac.Smoke.Indoor-(C.2)

The smoke layer in the space concerned satisfies:

$$S > 1.6 + 0.1H$$ (5.1.2.3)

where $S$: Height of the smoke layer interface from the floor of the evacuee [m]

$H$: Average ceiling height of the space from the floor of the evacuee [m]
5.1.2.4 Evac.Smoke.Indoor-(C.3)

Whichever of the following conditions (1) - (3) is satisfied any partition in every smoke propagation route from fire room to the evacuation space concerned.

(1) Pressure difference at openings or gaps in the partition concerned

\[ \Delta P(z) > 0 \quad (h_1 < z < h_2) \]  

(5.1.2.4-1)

where \( \Delta P(z) \) : Pressure difference of the evacuation side space relative to the fire room side space [Pa]

\( z \) : Height [m]

\( h_1 \) : Lower end height of an opening or a gap in the partition concerned [m]

\( h_2 \) : Upper end height of an opening or a gap in the partition concerned [m]

Pressure difference at an opening in a partition to stop smoke spread

(2) Smoke layer height in a fire room side space

\[ S > h_2 + 0.1(H - h_2) \]  

(5.1.2.4-2)

where \( S \) : Height of smoke layer interface from the floor of the fire room side space [m]

\( H \) : Average ceiling height of the fire room side space [m]

\( h_2 \) : Uppermost end height of the openings and gaps on the partition concerned [m]

Smoke layer height at a fire room side space to stop smoke spread

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

\[ \frac{A_E}{V} < \frac{0.8 \times 10^2}{\Delta T_s (t_2 - t_1)^{3/2} \sqrt{\Delta P}} \]  

(5.1.2.4-3)

where \( A_E \) : Maximum equivalent opening area in the partitions on smoke propagation route during the fire [m²]

\( V \) : Volume of the evacuation space concerned [m³]

\( \Delta T_s \) : Temperature rise in the fire room side space on smoke propagation route [K]

\( t_1 \) : Time when an evacuee begins to escape in the space [sec]

\( t_2 \) : Time when the evacuee finishes to escape in the space [sec]

\( \Delta P \) : Pressure difference of the fire room side space relative to the evacuation side space [Pa]
5.1.3 Acceptance Criteria for Safety of Evacuees from Smoke at the Outdoor

The outdoor space of a building where whichever of the following criteria: 5.1.3.1·5.1.3.3, is satisfied during the prescribed time is deemed to be at the acceptable level with regard to the safety of occupants from smoke.

5.1.3.1 Evac.Smoke.Outdoor-(P.)

The smoke to which any of evacuees is exposed in the space satisfies:

\[ \int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1.0 \times 10^4 \]  \hspace{1cm} (5.1.3.1-1)

where \( \Delta T \) : Temperature rise of the smoke to which the evacuee is exposed [K]
\( t_1 \) : Time when the concerned evacuee begins to be exposed to the smoke [sec.]
\( t_2 \) : Time when the concerned evacuee ceases to be exposed to the smoke [sec.]

5.1.3.2 Evac.Smoke.Outdoor-(C.1)

The smoke to which any of the evacuees is exposed in the space satisfies:

\[ (\Delta T_{\text{max}})^2 (t_2 - t_1) < 1.0 \times 10^4 \]  \hspace{1cm} (5.1.3.2-1)

where \( \Delta T_{\text{max}} \) : Maximum temperature rise of the smoke to which the evacuee is exposed [K]
\( t_1 \) : Time at which the evacuee begins to be exposed to the smoke [sec.]
\( t_2 \) : Time at which the evacuee ceases to be exposed to the smoke [sec.]

5.1.3.3 Evac.Smoke.Outdoor-(C.2)

The smoke to which any of the evacuees is exposed in the space satisfies all the following conditions (1) · (3):

(1) Concerning the location of the evacuation space relative to any opening that may eject smoke in the event of fire, either of the following conditions (i) · (iii) is satisfied.

(i) Height from the sill of the opening

\[ z < 0 \]  \hspace{1cm} (5.1.3.3-1)

where \( z \) : Height from the sill of the opening [m]

(ii) Horizontal distance perpendicular to the opening surface

\[ \frac{x}{H} > 0.6 \left( \frac{z}{H} \right)^{1/3} + 0.3 \left( \frac{z}{H} \right) \]  \hspace{1cm} (5.1.3.3-2)
where $H$ : Height of the opening [m]
$x$ : Horizontal distance from the opening that is perpendicular to its surface [m]
$z$ : Height from the lower end of the opening [m]

(iii) Horizontal distance parallel to the opening surface

$$\frac{y}{H} > 0.3 \left( \frac{z}{H} \right)$$ (5.1.3.3-3)

where $H$ : Height of the opening [m]
$x$ : Horizontal distance from the opening that is perpendicular to its surface [m]
$z$ : Height from the sill of the opening [m]

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

(3) 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.

5.1.4 Acceptance Criteria for the Safety of Evacuees from Radiant Heat

A space that satisfies either of the following criteria; 5.1.4.1-5.1.4.2, during the prescribed time is deemed to be at the acceptable level with regard to the safety of occupants from radiant heat due to fire.

5.1.4.1 Evac.Radiation-(P.)

The radiant heat to which any evacuees is exposed in the space satisfies:

$$\int_{t_1}^{t_2} I^2 dt < 2.5 \times 10^3$$ (5.1.4.1-1)

with

$$I = \begin{cases} 
q'' - 0.5 & (q'' > 0.5) \\
0 & (q'' \leq 0.5)
\end{cases}$$ (5.1.4.1-2)

where $q''$ : Incident radiant heat flux to the evacuee [kW/m$^2$]
$t_1$ : Time at which the evacuee begins to be exposed to the radiant heat [sec]
$t_2$ : Time at which the evacuee ceases to be exposed to the radiant heat [sec]
5.1.4.2 Evac.Radiation-(C.1)

The radiant heat to which any evacuees is exposed in the space satisfies:

\[ I_{max}^2 \left( t_2 - t_1 \right) < 2.5 \times 10^2 \]  

(5.1.4.2-1)

with

\[ I_{max} = \begin{cases} q_{max}^* - 0.5 & \left( q^* > 0.5 \right) \\ 0 & \left( q^* \leq 0.5 \right) \end{cases} \]  

(5.1.4.2-2)

where

- \( q_{max}^* \): Maximum incident radiant heat flux to the evacuee [kW/m^2]
- \( t_1 \): Time at which the evacuee begins to be exposed to the radiant heat [sec]
- \( t_2 \): Time at which the evacuee ceases to be exposed to the radiant heat [sec]

5.1.5 Acceptance Criteria for Safety of Evacuees from Falling Debris

A space where either of the following criteria: 5.1.5.1 and 5.1.5.2, is satisfied during the prescribed time is deemed to be at the acceptable level with regard to the safety of occupants from falling objects due to fire.

5.1.5.1 Evac.Debris-(C.1)

Any building element and the support members thereof satisfy the following conditions (1) and (2), respectively, during the prescribed time.

(1) The element satisfies all the following conditions:

\[ T < \min \left( T_{brk}, T_{mlt}, T_{ign} \right) \]  

(5.1.5.1-1)

where

- \( T \): Temperature of the element [K]
- \( T_{brk} \): Breakage temperature of the element [K]
- \( T_{mlt} \): Melting temperature of the element [K]
- \( T_{ign} \): Ignition temperature of the element [K]

(2) The support members of the element satisfy the criterion ‘5.2.2 Acceptance Criteria for Structural Stability in Fire’.

5.1.5.2 Evac.Debris-(C.2)

Any position in the concerning space is in the range that satisfies:

\[ D > \begin{cases} \sqrt{H} & \left( H \geq 0 \right) \\ 0 & \left( H < 0 \right) \end{cases} \]  

(5.1.5.2-1)

where

- \( D \): Horizontally projected distance of the space from the part of the building that may fall down in the fire [m]
- \( H \): Vertically projected distance of the space from the part of the building that may fall down in the fire [m]
5.1.5.3 Evac.Debris-(C.3)

Eaves, balcony, roof and the like part projected from an exterior wall, located below the part that may fall due to fire, satisfies the following conditions (1) and (2):

(1) Width of the projected part

\[ d > \sqrt{h} \]  \hspace{1cm} (5.1.5.3-1)

where

- \( d \) : Horizontal distance of the tip of the projected part from the part that may fall due to fire [m]
- \( h \) : Vertical distance of the tip of the projected part from the part that may fall due to fire [m]

(2) Strength of the projected part

The projected part can endure against the impact of the falling debris.
Notes for ‘Chapter 5 Common Acceptance Criteria - 5.1 Assurance of Life Safety’

N: 5.1 5.1 ASSURANCE of LIFE SAFETY

N: 5.1.1 Terminology

The safety criteria here intend to be commonly applied to the safety of evacuees, whether on an escape route or in a refuge. Hence, the 'evacuation space' means either an escape route or a refuge, and the 'evacuation time' means the travel time to pass a space on an escape route or the residence time in a refuge.

For the safety of evacuees from smoke in building fire, smoke barriers of various kinds that exist on the passage of smoke propagation play an important role. The terms of 'fire room side space' and 'evacuation side space' are introduced for convenience in dealing with the performance of the smoke barriers.

N: 5.1.2 Acceptance Criteria for Safety of Evacuees from Smoke in Building

N: 5.1.2.1 Evac.Smoke.Indoor-(P)

It will be clear and sound as the goal of evacuation safety design of a building to assure that no evacuee is exposed to smoke. In many design practices, it is technically possible to accomplish this design goal by means of an early stage alert or adequate smoke control systems.

However, it can be too difficult to achieve such a design goal under a certain fire scenarios. A space where many occupants are expected at upper positions above the floor of fire origin, such as a theater or an atrium, it is often difficult to verify that nobody is exposed to smoke, because smoke layer in a high ceiling space generally descend very quickly at the early stage. On the other hand, the temperature and concentration of the 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 period. As another example, considering a short corridor on an escaping route in which no smoke control system is installed, there may be no other evacuation scenario than to break through it, even if it is clogged with smoke. This performance criterion can accept such evacuation scenarios to a degree.

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

Regarding the exposure to toxic gases and temperature, the following equation called Harber’s law expressed as below is often used. That is

\[(X - X_0)(t - t_0) = \text{const.}\]  

(N5.1.2.1-1)

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. After some trials and consideration, it is decided here
that the form of equation as
\[(\Delta X)^2 t = \text{const.}\] \((N5.1.2.1-2)\)
is more appropriate as a conservative criterion considering exposures to elevated temperature and a
certain kinds of major toxic gases in fire.

In smoke control engineering area, smoke concentration diluted to 1/100 of that in the room of fire
origin is said to be at acceptable level in a staircase, although this value may not always be valid but
its validity depend on exposure time to smoke. It will roughly take 400sec. to get down the stairs at
free walking speed from the top to the bottom of a high-rise building of 100m of height. On the other
hand, if the temperature rise in the room of fire origin is about 1,000K and the temperature decrease
outside of the fire room is mainly de to dilution, it follows that the temperature rise of smoke diluted to
1/100 is roughly 10K. Smoke temperature in an actual situation also drops by heat loss to walls, etc. in
the course of its propagation within a building. If roughly assumed that 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 of that in the room of origin is 5 K. Using these values into Equation N5.1.2.1-2, we
have
\[(\Delta T)^2 t_{\text{vac}} = 5^2 \times 400 = 10,000\] \((N5.1.2.1-3)\)

The criterion in this standard is the generalization of this equation for accommodating transient
conditions. According to this criterion, 25 seconds of evacuation time is allowed if the temperature
rise is 20K(=20+room temp. °C), and only 1sec. if the temperature rise is 100K, for example.

For the judgment of smoke exposure to evacuees, it is taken into consideration that smoke behavior
is mostly predicted using one-layer or two-layer zone model in fire safety designs practices of actual
buildings. Since one-layer zone models only predict average temperature in a room, the judgment is
made by temperature rise of the room.

In the case two-layer zone models are used, the judgment is normally made based on smoke layer
interface height. Though a two-layer zone model assumes a clear discontinuity between an upper and
a lower layer, the 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 Japanese male is 172 cm, the condition that an evacuee is not exposed to smoke is
\[S - \frac{1}{10}(H - S) < 1.72\] \((N5.1.2.1-4')\)
that is
\[S < 1.56 + 0.09H\] \((N5.1.2.1-4)\)
where H is the ceiling height of the space.

The value of this standard is conservatively rounded up. The image of the application of this
standard is illustrated the figure below.
In view 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 is universally employed indifferent of height of space as the criterion, it can be too rigorous for low ceiling spaces, while it can be meaningless for very high ceiling spaces, in which case the clear height is almost within an error range. The term of 0.1H in this criterion intends to mitigate such contradictions.

N: 5.1.2.2 Evac.Smoke.Indoor-(C.1)

While the above Evac.Smoke.Indoor-(P) is a P-B criterion, which is able to accommodate transient change of temperature of smoke, \( \Delta T \), to which an evacuee is exposed, this is a complimentary criterion using the maximum temperature rise of the smoke, \( \Delta T_{\text{max}} \). This intends to be used more easily than Evac.Smoke.Indoor-(P), although naturally a bit severer.

N: 5.1.2.3 Evac.Smoke.Indoor-(C.2)

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

N: 5.1.2.4 Evac.Smoke.Indoor-(C.3)

N: (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 stopped if the pressure of the evacuation side space is positive relative to the fire room side space at any height, z, 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 \( \Delta P(z) > 0 \), where \( h_1 \) and \( h_2 \) are the sill and soffit heights, respectively. The concept of this standard is as illustrated as in the figure below. However, the possibility of exceptional temperature conditions cannot be totally neglected, so this complimentary criterion is expressed as above. The representative means to build such pressure difference is a mechanical smoke control but may not be limited to it.
N: (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 means that smoke does not invade into an evacuation side space if the smoke layer in the fire room side space is higher than the opening soffit in the partition. The figure below illustrates this concept. Incidentally, the second term in the right hand side of the above equation intends to cover, more or less, the blurred nature of smoke layer interface.

![Diagram of smoke layer height](image)

N: (3) **Air tightness of a partition or system of partitions along smoke propagation route**

Let’s imagine a situation where a partition, or a system of partitions, with some gaps separates the spaces on a smoke propagation route into the fire room side and the evacuation side. Smoke will flow into a space at the evacuation side through the gaps if the pressure at the fire room side space, contaminated with smoke, is positive relative to the evacuation space side. Noting that mass inflow and outflow rates for a space are generally the same at steady state, the conservation of smoke in the evacuation space is expressed by

\[
M \frac{dX}{dt} = m(X_0 - X)
\]  

\( (N5.1.2.4-1) \)

where
- \( X_0 \) : Concentration of smoke in the fire room side space [ - ]
- \( X \) : Concentration of smoke in the evacuation side space [ - ]
- \( M \) : Mass of air in the evacuation side space [kg]
- \( m \) : Mass flow rate of air into (=out of) the evacuation side space [kg/sec]
- \( t \) : Time [sec]

Integrating Equation \( N5.1.2.4-1 \) with initial condition: \( X=0 \) when \( t=0 \), and approximating the result, we obtain

\[
\frac{m}{M} t = - \ln \left( 1 - \frac{X}{X_0} \right) \approx \frac{X}{X_0}
\]  

\( (N5.1.2.4-2) \)

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

\[
\frac{X}{X_0} \approx \frac{\Delta T}{\Delta T_S}
\]  

\( (N5.1.2.4-3) \)
where \( \Delta T_s \) is the temperature rise of the smoke contaminated space. Then, using Equation N5.1.2.4-3 and the complimentary criteria ‘Evac.Smoke.Indoor-(C.1)’:

\[
(\Delta T)^3 (t_2 - t_1) < 1.0 \times 10^4
\]  

(N5.1.2.4-4)

Equation N5.1.2.4-2 becomes as follows:

\[
\frac{m}{M}(t_2 - t_1)^{3/2} < \frac{1.0 \times 10^2}{\Delta T_s}
\]  

(N5.1.2.4-5)

Letting \( \rho \) be the air density, \( M \) and \( m \) are given by

\[
M = \rho V \quad \text{and} \quad m = A_E \sqrt{2\rho \Delta P}
\]  

(N5.1.2.4-6)

Hence, finally

\[
\frac{A_E}{V} < \sqrt{\frac{\rho}{2}} \frac{1.0 \times 10^2}{\Delta T_s (t_2 - t_1)^{3/2}} \frac{1}{\sqrt{\Delta P}}
\]  

(N5.1.2.4-7)

Using \( \rho = 1.2 \) and rounding up the coefficient results the standard.

The necessary air tightness does not always have to be attained by a single partition. If there are multiple partitions between the smoke contaminated space and the evacuation space, which should be free from smoke, it is enough that the system of those partitions has the required air tightness. It is well known that the equivalent opening area of the openings, or leakages, in such partitions located in series can be calculated as

\[
A_E = 1/ \sqrt{\sum_{i=1}^{N} A_i^2}
\]  

(N5.1.2.4-8)

where \( A_i \) is the area of the opening in a partition, \( i \), and \( N \) is the number of the partitions in series. Incidentally, the pressure difference in this case is taken as the difference between the smoke contaminated space and the evacuation space as illustrated in the figure below.

![Effective air tightness of a series of openings](image)

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 stopped at somewhere on every route. For this purpose, any of the methods: (1) through (3) can be employed for each of the routes, but, when multiple methods are combined, sufficient consideration is necessary on the adversary effects due to their interactions.

**N: 5.1.3 Acceptable Criteria for the Safety of Evacuees from Smoke at Outdoor**

**N: 5.1.3.1 Evac.Smoke.Outdoor-(P)**

This criterion is similar to ‘Evac.Smoke.Indoor-(P)’ in ‘5.1.2 Acceptance Criteria for Safety of Evacuees from Smoke in Building’. However, at the outside of a building, it is difficult to generalize
the conditions to decide when an evacuee is exposed to smoke. A typical scenario of smoke exposure of evacuees may be such that a fire occurs on a floor in an apartment building with open air corridors and occupants on upper floors have to escape, breaking through the corridors that are partly exposed to smoke from the fire room, on a floor below. In such a case, $t_1$ in the criterion 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.

N: 5.1.3.2 Evac.Smoke.Outdoor-(C.1)

This criterion is similar to ‘Evac.Smoke.Indoor-(C.1)’ in ‘5.1.2 Acceptance Criteria for Safety of Evacuees from Smoke in Building’, although the scenarios of smoke exposure are somewhat different, as mentioned in the note for ‘Evac.Smoke.Indoor-(P.)’.

N: 5.1.3.3 Evac.Smoke.Outdoor-(C.2)

Fire gases contain various harmful substances, such as heat, toxic gases and smoke particles. However, after having come out to the open air, their hazardous level will considerably go down due to the mixing with fresh air, so an evacuation space at sufficiently downstream of the openings of a fire room will be safe enough. Since it is not always easy enough for a usual engineer to calculate the temperature of window plume, a complementary criterion is introduced here, for convenience of practical evaluation, so that the hazard due to a window jet from a fire-resistive building can be readily treated, unless the location of the evacuation space is exceptional.

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

$$\frac{x}{H} = 0.6 \left( \frac{z}{H} \right)^{1/3} \quad (N5.1.3.3-1)$$

where $x$ and $y$ are the horizontal and the vertical distances from the ejecting point of the 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 a window plume, and the height $z$ is taken from the lower end of opening for simplicity and conservative estimation, so that

$$\frac{x}{H} > 0.6 \left( \frac{z}{H} \right)^{1/3} + 0.3 \left( \frac{z}{H} \right) \quad (N5.1.3.3-2)$$

Here the value of 0.3 is thought to be at sufficiently safer side, considering that the value for the half-width of a usual fire the plume is said to be 0.13 from Zukoski and 0.15 from Hasemi. Although it is necessary to take into account that the temperature distribution naturally develops beyond the half-width, and that turbulence due to wind may cause wider diffusion of a plume, the temperature at 0.3(z/H) will be significantly low.

N: 5.1.4 Acceptable Criteria for the Safety of Evacuees from Radiant Heat

N: 5.1.4.1 Evac.Radiation-(P.)

Let’s imagine the example that a part of wall of an evacuation space, such as a staircase or a corridor, is made of wired glass or metal panels. The wall might not break by fire but transmit
heat and the room behind the wall can be a potential fire room. In the event of fire, evacuees in the evacuation space may 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 judgment of evacuation safety but there can be many other cases in which radiant heat to evacuees becomes to be an issue.

Typical scenario of radiant heat exposure

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

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

(N5.1.4.1-1)

where \( k \rho c \) is the thermal inertia of human body and \( t \) is the time[4].

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

\[ I^2 t = \text{const.} \]  

(N5.1.4.1-2)

Since \( I \) in Equation N5.1.4.1-2 is net radiant heat, it is necessary to deduct from incident radiant heat flux, \( q' \), the heat loss from a human body:

\[ \sigma T_{\text{body}}^4 = 5.67 \times 10^{-11} \times (273 + 36)^4 \approx 0.5 \ [\text{W/m}^2] \]  

(N5.1.4.1-3)

where \( \sigma \) and \( T_{\text{body}} \) are Stefan-Boltzmann constant and temperature of human body, respectively.

The right hand side term of Equation N5.1.4.1-2 is determined based on the existing experimental results[5] with consideration of some safety margin.

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

\[ t = \frac{B}{v} \]  

(N5.1.4.1-4)

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 \( q' \).

N: 5.1.4.2 Evac.Radiation-(C.1)

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.
N: 5.1.5 Acceptance Criteria for Safety of Evacuees from Falling Debris

N: 5.1.5.1 Evac.Debris-(C.1)

Refuge, evacuation route, fire-fighting 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 (1) building element and (2) 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 roof supporting member is usually designed according to relevant structural design method so the stability can be verified by the criterion '5.2.2 Acceptance Criteria for Structural Stability in Fire'.

N: 5.1.5.2 Evac.Debris-(C.2)

As an example, in case a refuge is somewhat remote from the building on fire, danger would not reach occupants therein even if the fire causes falling debris. Though not ample knowledge is available for sufficient distance to ensure safety of a space from falling debris, it is considered here as follows:

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

\[
x = u_0 t \\
y = \frac{1}{2} gt^2
\]

where $u_0$ : Initial horizontal velocity of the falling debris [m/sec.]
$g$ : Gravity acceleration [m/sec.2]
$t$ : Time [sec.]
$x$ : Horizontal distance [m]
$y$ : 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

\[
x = 0.45u_0 \sqrt{H}
\]

Though it is difficult to determine the initial velocity $u_0$, let’s imagine the case that glass panes of the room of origin breaks, 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 equation holds
\[ F = \Delta PA = ma \]  

(N5.1.5.1-4)

where \( \alpha \) is the acceleration, \( A \) is the area of the pane piece and \( \Delta P \) is the pressure difference.

Letting \( h \) be the height of the window soffit from neutral pressure zone, \( \Delta P \) is about the order of

\[ \Delta P \approx \Delta \rho gh \]  

(N5.1.5.1-5)

From Equations N5.1.5.1-4 and N5.1.5.1-4

\[ \alpha \approx \frac{\Delta PA}{m} = \frac{\Delta \rho ghA}{\rho_{GLS} dA} \]  

(N5.1.5.1-6)

where \( \rho_{GLS} \) is the glass density (=2200 kg/m\(^3\)) and \( d \) is the thickness (=0.5cm).

Glass pane may 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, \( \alpha = (1/15)gh \) is obtained. If the force, \( F \), applies to the glass piece during it falls in the window jet, the duration is order of

\[ t \approx \sqrt{2h/g} \]  

(N5.1.5.1-7)

Therefore, the velocity \( u_0 \) at which it leaves from the window jet becomes as

\[ u_0 = \alpha t = \frac{1}{15} ght = \frac{\sqrt{2g}}{15} h^{3/2} \]  

(N5.1.5.1-8)

Conservatively assuming window height as 3m, so \( h \) is approximately 2m, the initial velocity \( u_0 \) is calculated to be \( u_0 = 0.83 \) m/s. Therefore, from Equation N5.1.5.1-3, the horizontal distance \( x \) becomes:

\[ x \approx 0.37\sqrt{H} \]  

(N5.1.5.1-9)

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, despite their initial velocities may be small and influence of wind may 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 that the required distance is about 3m for a 10m high building and 10m for a 100m high building.

N: 5.1.5.3 Evac.Debris-(C.3)

This criterion is based on the same consideration as the above C.2 - Evac.Debris.
5.2 Structural Stability and Preventing Trouble to Neighborhood Due to Collapse

5.2.1 Terminology

5.2.1.1 Structural stability
State of a structure at which no excessive movement and/or deformation is caused by an external force that acts thereto.

5.2.1.2 Long time design loading
External load that is assumed, in a structural design, to act to a structure at all time, such as fixed loads and live loads.

5.2.1.3 Impact to the neighborhood
Damage, nuisance, disturbance of normal order of life, etc., that are caused to the persons and/or the community in the vicinity of a building.

5.3.1.4 Allowable stress
Limit stress for structural design purpose that is set to assure that stress caused in a structural member by external load does not exceed the yield stress thereof.

5.4.1.5 Yield strength
Strength at which a structural member subjected to a loading begins to be apart from hook’s law.

5.2.2 Acceptance Criteria for Structural Stability in Fire
A building that complies with whichever of the following criteria: 5.2.2.1-5.2.2.4, during the prescribed time is deemed to be at the acceptable level with respect to structural stability in fire.

5.2.2.1 Struct. Stability-(P.)
Every load bearing member satisfies both of the following conditions (1) and (2):

(1) Axial strength in fire
\[ P(T) > P_D \]  \hspace{1cm} (5.2.2.1-1)
where \( P(T) \) : Axial strength of the load bearing member when exposed to the fire [N]
\( P_D \) : Axial force under long time design loading [N]

(2) Bending strength in a fire time
\[ M(T) > M_D \]  \hspace{1cm} (5.2.2.1-2)
where \( M(T) \) : Bending strength of the load bearing member when exposed to fire [Nmm]
\( M_D \) : Bending moment under long time design loading [Nmm]
5.2.2.2 Struct. Stability-(C.1)

In the case of a steel structure, every load bearing member satisfies both of the following conditions (1) and (2):

(1) The axial strength satisfies both of the following conditions (i) and (ii):

(i) Axial compressive strength

\[ P_c(T) > P_D \]  \hspace{1cm} (5.2.2.2-1)

where  
- \( T \): Temperature of the load bearing steel member [K]
- \( P_c(T) \): Axial compressive strength of the load bearing steel member at temperature \( T \) [N]
- \( P_D \): Axial force due to the long time design loading [N]

where \( P_c(T) \) is calculated by

\[ P_c(T) = A_c \cdot \sigma_y(T) \]  \hspace{1cm} (5.2.2.2-2)

where  
- \( A_c \): Cross sectional area of the load bearing steel member [mm²]
- \( \sigma_y(T) \): Effective yield strength of the load bearing member at temperature \( T \) [N/mm²]

(ii) Axial buckling strength in fire

\[ P_B(T) > P_D \]  \hspace{1cm} (5.2.2.2-3)

where  
- \( T \): Temperature of the load bearing steel member [K]
- \( P_B(T) \): Buckling strength of the load bearing steel member at temperature \( T \) [N]
- \( P_D \): Effective buckling force due to the long time design loading [N]

where \( P_B(T) \) is calculated by

\[ P_B(T) = A_c \cdot \sigma_{cr}(T) \]  \hspace{1cm} (5.2.2.2-4)

where  
- \( A_c \): Cross sectional area of the load bearing steel member [mm²]
- \( \sigma_{cr}(T) \): Buckling stress of the load bearing steel member at temperature \( T \) [N/mm²]

where \( \sigma_{cr}(T) \) is calculated by

\[ \sigma_{cr}(T) = \begin{cases} 
1 - 0.4\left(\frac{\lambda}{\Lambda}\right)^2 \sigma_y(T) & (\lambda \leq \Lambda) \\
0.6 \sigma_y(T) & (\lambda > \Lambda) 
\end{cases} \]  \hspace{1cm} (5.2.2.2-5)

where  
- \( \lambda \): Slender ratio ( = buckling length / radius of gyration) [-]
- \( \sigma_y(T) \): Yield stress of the load bearing steel members at temperature \( T \) [N/mm²]
- \( \Lambda \): Limit slender ratio at room temperature [N/mm²]

where the limit slender ratio \( \Lambda \) at room temperature is given by

\[ \Lambda = \frac{\pi^2 E}{96 \sigma_y} \]  \hspace{1cm} (5.2.2.2-6)
where $E$ : Young’s modulus of the steel member at room temperature [N/mm$^2$]
$\sigma_y$ : Yield stress of the steel at room temperature [N/mm$^2$]

(2) The bending strength satisfies the following conditions:

(i) Bending strength

$$M(T) > M_B$$  
(5.2.2.2-7)

where $T$ : Temperature of the load bearing member (steel member) [K]
$M(T)$ : Bending strength of the load bearing member at temperature $T$ [Nmm]
$M_B$ : Bending moment due to the long time design loading [Nmm]

where $M(T)$ is calculated by

$$M(T) = Z_{px} \cdot \sigma_y(T)$$  
(5.2.2.2-8)

where $Z_{px}$ : Plastic section modulus of the load bearing member [mm$^3$]
$\sigma_y(T)$ : Yield stress of the load bearing member at temperature $T$ [N/mm$^2$]

(ii) 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 the load bearing member at temperature $T$, $\sigma_y(T)$, in the formulas in (1) and (2) shall be estimated by the following (A) or (B).

(A) 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 the following formula.

$$\sigma_y(T) = \begin{cases} 
\bar{\sigma}_y & (T \leq T_1) \\
\frac{\bar{\sigma}_y}{T_2 - T_y} \cdot T_2 - T & (T_1 < T \leq T_2) \\
0 & (T_2 < T)
\end{cases}$$  
(5.2.2.2-9)

where $\bar{\sigma}_y$ : Standard stress of the steel member at room temperature [N/mm$^2$]
$T$ : Temperature of the steel member in fire [°C]
$T_1$ : Temperature at which the strength of steel begins to decrease (=325° C )
$T_2$ : Temperature at which the strength of steel becomes zero (=700 °C)

Yield stress of structural steel as a function of temperature, $\sigma_y(T)$
(B) Yield strength of 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.

5.2.2.3 Struct. Stability-(C.2)

In the case of a reinforced concrete structure, every load bearing member satisfies both of the following criteria: (1) and (2):

1. Axial compressive strength

\[ P_c(T) > P_D \]  \hspace{1cm} (5.2.2.3-1)

where \( P_c(T) \) : Axial compressive strength of the load bearing member in fire [N]

\( P_D \) : Axial force due to long time design loading [N]

where \( P_c(T) \) is calculated by

\[ P_c(T) = A_{CT} \cdot \bar{\sigma}_a \]  \hspace{1cm} (5.2.2.3-2)

where \( A_{CT} \) : Cross sectional area of the load bearing member excluding the depth where the temperature exceeds 500 °C [mm²].

\( \bar{\sigma}_a \) : Standard stress of the load bearing member at room temperature [N/mm²] provided that the depth over 500 °C shall not exceed 2 x covering thickness of reinforcing bars.

2. Regarding bending strength in fire, a beam whose compressed part is exposed to fire satisfies the following condition (i), and a beam whose tensile part is exposed to fire satisfies the following condition (ii). Nevertheless, a structural frame whose stresses may be re-distributed can be verified based on the re-distributed stresses.

   (i) A beam whose compressed side is exposed to fire

\[ M_e(T) > M_D \]  \hspace{1cm} (5.2.2.3-3)

where \( M_e(T) \) : Bending strength at compressed part of the load bearing member in fire [Nmm]

\( M_D \) : Bending moment at compressed part of the member due to long time design loading [Nmm]

where \( M_e(T) \) is calculated by

\[ M_e(T) = a_t \cdot f_t(T) \cdot j_e \]  \hspace{1cm} (5.2.2.3-4)

where \( a_t \) : Cross sectional area of the tensile reinforcing bars [mm²]

\( f_t(T) \) : Allowable stress of the tensile reinforcing bars in fire [N/mm²]

\( j_e \) : Effective depth of the load bearing member [mm]

where \( j_e \) is calculated by

\[ j_e = \frac{7}{8} (D - d_c) \]  \hspace{1cm} (5.2.2.3-5)

where \( D \) : Depth of the load bearing member [mm]
\( d_c \) : 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 x the covering thickness of reinforcing bars.

(ii) A beam whose tensile side is exposed to fire

\[ M_c(T) > M_D \]  \hspace{1cm} (5.2.2.3-6)

where \( M_c(T) \) : Bending strength at the tensile part of the load bearing member in fire [Nmm]

\( M_D \) : Bending moment due to long time design loading [Nmm]

where \( M_c(T) \) is calculated by

\[ M_c(T) = a_c \cdot f_c(T) \cdot j_e \]  \hspace{1cm} (5.2.2.3-7)

where \( a_c \) : Cross sectional area of the tensile reinforcing bars [mm²]

\( f_c(T) \) : Allowable stress of the tensile reinforcing bars in fire [N/mm²]

\( j_e \) : Effective depth of the load bearing member [mm]

where \( j_e \) is calculated by

\[ j_e = \frac{7}{8} d \]  \hspace{1cm} (5.2.2.3-8)

where \( d \) : Distance from the upper surface of the load bearing member to the center of the tensile reinforcing bars [mm]

provided that the yield strength of the load bearing member \( f_c(T) \) in the above (i) and (ii) are estimated by the following (A) or (B):

(A) 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 the following formula.

\[ f_c(T) = \begin{cases} 
\frac{f_t}{T_2 - T_1} & (T \leq T_1) \\
\frac{f_t}{T_2 - T_1} \frac{T_2 - T}{T_2 - T_1} & (T_1 < T \leq T_2) \\
0 & (T_2 < T)
\end{cases} \]  \hspace{1cm} (5.2.2.3-9)

where \( f_t \) : Standard strength of reinforcing bars at room temperature [N/mm²]

\( T \) : Temperature of reinforcing bars in fire [°C]

\( T_1 \) : Temperature at which the strength of reinforcing bars begin to decrease (=325 °C)

\( T_2 \) : Temperature at which the strength of reinforcing bars becomes zero (=700 °C)

(B) Yield strength of 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.
5.2.2.4 Struct. Stability-(C.3)

In the case of wooden structure, every load bearing member satisfies both of the following conditions (1) and (2):

(1) Axial strength in fire satisfies both of the following conditions (i) and (ii).

        (i) Axial compressive strength

        \[ P_{c}(T) > P_{D} \]  
        
        where \( P_{c}(T) \) : Axial compressive strength of the load bearing wooden member in fire [N].
        \( P_{D} \) : Axial force due to long time design loading [N]

        where \( P_{c}(T) \) is calculated by

        \[ P_{c}(T) > A_{c} \cdot \sigma_{y} \]  

        where \( A_{c} \) : Cross sectional area of the load bearing wooden member excluding charred part [mm\(^{2}\)]
        \( \sigma_{y} \) : Allowable compressive stress of the load bearing wooden member at room temperature [N/mm\(^{2}\)]

        (ii) Axial buckling strength in fire

        \[ P_{B}(T) > P_{D} \]  

        where \( B(T) \) : Buckling strength of the load bearing wooden member in fire [N]
        \( P_{D} \) : Effective buckling force due to long time design loading [N]

        where

        \[ P_{B}(T) = A_{c} \cdot \sigma_{cr} \]  

        where \( A_{c} \) : Cross sectional area of the load bearing wooden member excluding charred part [mm\(^{2}\)]
        \( \sigma_{cr} \) : Buckling stress of the load bearing wooden member in fire [N/mm\(^{2}\)]

        where \( \sigma_{cr} \) is calculated by

        \[ \sigma_{cr}(T) = \begin{cases} \left(1 - 0.4 \left( \frac{L}{\Lambda} \right)^{2}\right) \sigma_{y} & (\Lambda < \lambda) \\ 0.6 \sigma_{y} & (\Lambda > \lambda) \end{cases} \]  

        where \( \lambda \) : Slender ratio (~buckling length / radius of gyration) [-]
        \( \sigma_{y} \) : Yield compressive stress of the load bearing member at room temperature [N/mm\(^{2}\)]
        \( \Lambda \) : Limit slender ratio (~\(\sqrt{\pi E / 0.6 \sigma_{y}}\)) [-]
        \( E \) : Young's modulus of the load bearing wooden member at room temperature [N/mm\(^{2}\)]

(2) Bending strength in fire
\[ M(T) > M_D \]  \hspace{1cm} (5.2.2.4-6)

where \( M(T) \) : Bending strength of the load bearing wooden member in fire [N/mm]

\( M_D \) : Bending moment due to long time design loading [N/mm]

where \( M(T) \) is calculated by

\[ M(T) = Z_x \cdot \overline{\sigma}_y \]  \hspace{1cm} (5.2.2.4-7)

where \( Z_x \) : Section modulus of the load bearing wooden member excluding charred part [mm³]

\( \overline{\sigma}_y \) : Allowable bending stress of the load bearing wooden member at room temperature [N/mm²]

5.2.3 Acceptance Criteria for Prevention of Trouble to the Neighborhood due to Collapse

A building that complies with whichever of the following criteria: 5.2.3.1-5.2.3.3, is deemed to be at the acceptable level with respect to prevention of trouble to the neighborhood due to collapse thereof.

5.2.3.1 Trouble.Collapse-(D.1)

Every part of the building satisfies the following condition:

\[ H < d \]  \hspace{1cm} (5.2.3.1-1)

where \( H \) : Height of the part of the building from the site level [m]

\( d \) : Minimum horizontal distance from the concerning part to the site boundary [m]

5.2.3.2 Trouble.Collapse-(D.2)

Dimensions of the building satisfy both of the following conditions (1) and (2):

(1) Geometric condition not to overturn even if bearing members collapse.

\[ D > \sqrt{(H-h)h} \]  \hspace{1cm} (5.2.3.2-1)

where \( H \) : Height of the building [m]

\( D \) : Length of the shorter side of the building [m]

\( h \) : Maximum of the floor heights of the building [m]

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

\[ s < d \]  \hspace{1cm} (5.2.3.2-2)

where \( s \) : Horizontal displacement of the part of building due to leaning [m]

\( d \) : Minimum horizontal distance from the part to the site boundary [m]

5.2.3.3 Trouble.Collapse-(E)

From the particular conditions of the building concerned, it is deemed that the building would not fall down onto neighbor site by fire.
Notes for ‘Chapter 5: 5.2 Structural Stability and Preventing Trouble to Neighborhood Due to Collapse’

N:5.2.1 Terminology

N:5.2.2 Acceptance Criteria for Structural Stability in Fire

N:5.2.2.1 Struct.Stability-(P)

Generally, a loading causes compressive stress and bending stress in building structural members, such as columns or beams. Naturally, structural members are so designed as to be strong enough to put up with the loads in normal time. In the event of fire, however, a structural member may not be able to bear the load so may collapse, because of the deterioration of the strength due to fire heating.

Several ways are conceivable as the means to prevent the collapse of a structural member by fire: For example, use fire insulation to protect the member from undue temperature rise, or to design them with some margin taking into account their deterioration due to temperature rise. Fire resistance design for steel structures is based on the former idea and the large section timber structures is based on the latter idea.

This P-B criterion is so expressed as to be commonly applicable regardless of the type of structures. It should be noted that condition (I), relating to the axial strength, is applied not only to simple compressive failure but also to buckling failure of long columns, although not explicitly mentioned.

N:5.2.2.2. C.1-Struct.Stability-(C.1)

The deterioration of the strength of a steel structure is mainly caused by the decrease of yield strength and Young’s modulus as a result of temperature rise. A buckling is most likely to occur for a column with large slenderness ratio. This complementary criterion interprets the above P-B criterion Struct.Stability-(P) more explicitly for steel structures.

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, this criterion for bending strength must be satisfied both at the middle and the edges of a member.

To make sure, temperature T in $\sigma(T)$, $E(T)$, etc., does not mean fire temperature itself but means the temperature of members, elevated by fire heating.

N: 5.2.2.3 Struct.Stability-(C.2)

In the design of a reinforced concrete structure, reinforcing bars are counted only for bearing tensile stress but ignored for the compressive stress, while bearing strength of concrete is counted only for compressive stress but ignored for tensile stress.

The yield strength of a reinforcing bar is deteriorated by temperature rise in fire, like a steel member. Though the strength of concrete at high temperature 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 ºC, but becomes zero over 500 ºC. Therefore, a member to bear compressive loads, such as a column, needs to sustain a long time design load only by the residual sound part, excluding the part over 500 ºC, where 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, the lower part is in compression.

Considering a case that a reinforced concrete beam is heated in the tensile side, its load bearing ability, owing to the bending stress in the beam, may deteriorate due to the temperature rise of the reinforcing bars in tensile side. Though the heated part of the concrete also deteriorates, the tensile stress of concrete is disregarded and the load bearing ability of a beam in fire is evaluated only based on the strength of reinforcing bars in design of concrete beam. Since the compressive strength of concrete is degraded when a beam is heated at compressive side, the strength at temperatures over 500 ºC is neglected. The decrease of strength of reinforcing bars at tensile side, when the temperature rise reaches there, is also taken into consideration.

**N: 5.2.2.4 Struct.Stability-(C.3)**

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

**N:5.2.3 Acceptance Criteria for Prevention of Trouble to the Neighborhood due to Collapse**

**N:5.2.3.1 Trouble.Collapse-(D.1)**

This is a criterion to verify the compliance with the requirements for prevention of the impacts to the neighborhood in a simple manner. It is not easy to predict collapsing behavior of a building. However, should a building collapses and overturns, the impacts to the neighborhood would be minimal if the building fall within its lot. Actually it will be very rare that a building overturns, so this criterion must be significantly conservative.

**N:5.2.3.2 Trouble.Collapse-(D.2)**

If the floor area of a building is large relative to its height, it may lean but never overturns even if its columns or bearing walls collapse. The most disadvantageous scenario for the overturn of a building is that all the columns at one side on the ground level collapse all together to slant the building. The criterion (1) gives the condition that gravity center of a slant building stays within the range of the floor area. This is derived only considering a static force situation, so dynamic effects and movement of live loads at the time of leaning are ignored. However, columns on the other side may work to hold back the slant, so it is thought to be a reasonable criterion for a first order judgment.

If a building leans, a part of a building may overhang toward a neighbor site. The condition (2) is
to prohibit any part of a building to protrude out to third party’s property. For simple configurations, the length of overhang may be calculated. However, shape and other conditions of buildings may vary from one to another, so the length should be determined based on the conditions of a specific building.

N:5.2.3.3 Trouble.Collapse-(E.)

Though the above-mentioned two criteria describe conveniently usable conditions, there must be many cases that a building can be judged not to overturn to neighboring sites by fire, if the specific conditions of shape or structure are closely examined. Since it is too difficult to generalize such conditions to produce a common standard, the judgment is left to the discretion of appropriate experts.
5.3 Prevention of Fire Spread

5.3.1 Terminology

5.3.1.1 Adjacent building

Building in neighbor of the building concerned that is owned by others or rented to tenants.

5.3.1.2 Adjacent space

Space that is separated from the space of fire origin by walls, floor slabs, or free spaces.

5.3.2 Acceptance Criteria for Prevention of Fire Spread to Adjacent Buildings by Fire Radiation

A building that complies with either of the following criteria: 5.3.2.1 - 5.3.2.2, during the prescribed time of fire is deemed to be at the acceptable level with respect to safety performance for preventing fire spread to neighbor buildings due to fire radiation.

5.3.2.1 Firespread.to.Bldg.by.Radiation-(P.)

The radiation from the building satisfies both of the following conditions (1) and (2):

1. The radiant heat flux to any point at 3m in recess into adjacent sites from the property line satisfies

\[ \int_{t_D}^{t_0} q_{3}^{*2} dt \leq 2.0 \times 10^3 \]  

(5.3.2.1-1)

where \( q_{3}^{*} \): The radiant heat flux to any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [kW/m²]

\( t_D \): Prescribed time of fire [min]

2. The radiant heat flux to any point at 0.5m in recess into adjacent sites from the property line satisfies:

\[ \int_{t_D}^{t_0} q_{0.5}^{*2} dt \leq 3.2 \times 10^4 \]  

(5.3.2.1-2)

where \( q_{0.5}^{*} \): The radiant heat flux to any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [kW/m²]

\( t_D \): Prescribed time of fire [min]

Nonetheless, none of the above conditions (1) and (2) has to be satisfied for property line between roads, parks, riverbeds, agricultural fields, forests or the like spaces, where no buildings is expected to be constructed.

5.3.2.2 Firespread.to.Bldg.by.Radiation-(C.)

The radiation from the building satisfies both of the following conditions: (1) and (2) :

\[ \int_{t_D}^{t_0} q_{3}^{*2} dt \leq 2.0 \times 10^3 \]  

(5.3.2.2-1)

\[ \int_{t_D}^{t_0} q_{0.5}^{*2} dt \leq 3.2 \times 10^4 \]  

(5.3.2.2-2)
(1) The radiant heat flux to any point at 3m in recess into adjacent sites from the property line satisfies:

\[ q^*_{3} \leq 10 \] (5.3.2.2-1)

where \( q^*_{3} \) : The radiant heat flux to any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [kW/m²]

(2) The radiant heat flux to any point at 0.5m in recess into adjacent sites from the property line satisfies:

\[ q^*_{0.5} \leq 40 \] (5.3.2.2-2)

where \( q^*_{0.5} \) : The radiant heat flux to any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [kW/m²]

Nonetheless none of the above conditions (1) and (2) has to be satisfied for property line between roads, parks, riverbeds, agricultural fields, forests or the like spaces, where no buildings is expected to be constructed.

5.3.3 Acceptance Criteria for Prevention of Fire Spread to Adjacent Buildings by Window Flames

A building that complies with either of the following criteria: 5.3.3.1 - 5.3.3.2, during the prescribed time is deemed to be acceptable with respect to prevention of causing fire spread to neighboring buildings by window flames.

5.3.3.1 Firespread.to.Bldg.by.Flames-(C.1)

The flames from the building satisfy both of the following conditions: (1) and (2):

(1) The temperature of the window jet at 3m in recess into adjacent sites from the property line satisfies

\[ \Delta T_{3} < 100 \] (5.3.3.1-1)

where \( \Delta T_{3} \) : Maximum temperature rise of the window jet from the building of fire origin at any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [K]

(2) The temperature of the window jet at 0.5m in recess into adjacent sites from the property line satisfies

\[ \Delta T_{0.5} < 400 \] (5.3.3.1-2)

where \( \Delta T_{0.5} \) : Maximum temperature rise of the window jet from the building of fire origin at any point on the vertical surfaces on the lines that are parallel to and 3m in recess into adjacent sites from the property line [K]

Nonetheless none of the above conditions (1) and (2) has to be satisfied for property
5.3.3.2 Firespread.to.Bldg.by.Flames-(C.2)

The flames from the building satisfy both of the following conditions (1) and (2):

(1) Any opening of the building and its distance from the site boundary

\[
\frac{3 + d}{H} > 1.1 \left( \frac{B}{H} \right)^{2/15} \quad (5.3.3.2-1)
\]

and

\[
0.5 + \frac{d}{H} > 0.8 \left( \frac{B}{H} \right)^{2/15} \quad (5.3.3.2-2)
\]

where
- \( B \) : Width of the opening that may eject flames in the event of fire [m]
- \( H \) : Height of an opening that may eject flames in the event of fire [m]
- \( D \) : Minimum distance from the opening to the site boundary [m]

(2) No crack or burn through is caused in the exterior walls of the fire compartment during the prescribed time.

Nonetheless, none of the above conditions: (1) and (2) has to be satisfied for property line between roads, parks, riverbeds, agricultural fields, forests or the like spaces, where no buildings is expected to be constructed.

5.3.4 Acceptance Criteria for Prevention of Fire Spread to Adjacent Spaces

A space that satisfies the following criteria: 5.3.4.1, during the prescribed time is deemed to be acceptable with respect to prevention of causing fire spread to adjacent spaces.

5.3.4.1 Firespread.to.Room-(P)

A space satisfies the following conditions: (1) - (3):

(1) The surface temperature of any compartment wall at the adjacent space side satisfies:

\[ \Delta T_b < 230 \quad (5.3.4.1-1) \]

where \( \Delta T_b \) : Temperature rise of the surface of any compartment wall, floor slab or other at the adjacent space side [K]

(2) The radiant heat into the adjacent space through any opening satisfies either of the following conditions: (A) or (B):

(A) Radiant heat flux through the opening into the adjacent space satisfies:

\[ \int_{t_p}^{t_d} q''^2 dt \leq 2.0 \times 10^3 \quad (5.3.4.1-2) \]

where
- \( q'' \) : Radiant heat flux through the opening into the adjacent space [kW/m²]
- \( t_p \) : Prescribed time [min]
(B) Maximum radiant heat flux through the opening into the adjacent space satisfies

\[ q''_{\text{max}} < 10 \]  

(5.3.4.1-3)

where \( q''_{\text{max}} \): Maximum radiant heat flux through the opening into the adjacent space [kW/m²]

3) Regarding the transmission of flames or brands, both of the following conditions: (A) and (B) are satisfied

(A) No flame or brand enters into the adjacent room through any opening.

(B) No damage, crack or burn through that transmit flames is caused in the compartment wall, floor slab or opening between the adjacent rooms

5.3.5 Acceptance Criteria for Prevention of Receiving Fire Spread from Adjacent Buildings by Fire Radiation

A building that satisfies either of the following criteria: 5.3.5.1 - 5.3.5.2, during the prescribed time is deemed to be acceptable with respect to prevention of receiving fire spread from neighbor buildings by radiant heat.

5.3.5.1 Firespread.from.Bldg.by.Radiation·(P.)

All the following conditions: (1) · (3) are satisfied:

(1) The incident radiant heat flux into the interior of the building, through any opening or exterior wall, satisfies:

\[ q'' < 10 \left( 1 + \frac{1}{A} \right) \]  

(5.3.5.1-1)

where \( q'' \): Incident radiant heat flux, through the opening or exterior wall, into the interior of the building [kW/m²]

\( A \): Area of the opening or exterior wall of the building [m²]

(2) The temperature of any exterior member of the building, such as an opening, exterior wall or eaves, that is exposed to the radiant heat satisfies:

\[ T_w < T_{wg} \]  

(5.3.5.1-2)

where \( T_w \): Temperature of the exterior member [K]

\( T_{wg} \): Ignition temperature of the exterior member exposed to the radiant heat [K]

(3) No crack or burn through is caused to the exterior members of the building, such as an opening, exterior wall or eaves.

5.3.5.2 Firespread.from.Bldg.by.Radiation·(C.1)

All the following conditions: (1) · (3) are satisfied:

(1) The incident radiant heat flux into the interior of the building, through an opening or an exterior wall, satisfies:

\[ q'' < 10 \left( 1 + \frac{1}{A} \right) \]  

(5.3.5.2-1)
where $q''$: Incident radiant heat flux, through the opening or exterior wall, into the interior of the building [kW/m$^2$]

$A$: Area of the opening or exterior wall of the building [m$^2$]

(2) The incident heat flux to the exterior member of the building, such as an opening, an exterior wall or an eaves, that is exposed to the radiant heat satisfies:

$$q''_m < q''_ig$$

(5.3.5.2-2)

where $q''_m$: Incident radiant heat flux to the exterior member [kW/m$^2$]

$q''_ig$: Critical ignition heat flux to the exterior member [kW/m$^2$]

(3) No crack or burn through is caused to the exterior member of the building, such as an opening, an exterior wall or an eaves.

5.3.6 Acceptance Criteria for Prevention of Receiving Fire Spread from Adjacent Buildings by Window Flames

A building that satisfies either of the following criteria: 5.3.6.1-5.3.6.2 during the prescribed time is deemed to be acceptable with respect to prevention of receiving fire spread by window flames from neighbor buildings.

5.3.6.1 Firespread.from.Bldg.by.Flames-(P.)

Both of the following conditions: (1) and (2) are satisfied:

(1) The temperature of any exterior member of the building, such as an opening, an exterior wall or an eaves, that is exposed to flames or hot gases from openings satisfies:

$$T_W < T_{ig}$$

(5.3.6.1-1)

where $T_W$: Temperature of the exterior member of the building [K].

$T_{ig}$: Critical ignition temperature of the exterior member of the building [K].

(2) No crack or burn through is caused to any exterior member of the building, such as an opening, an exterior wall or an eaves.

5.3.6.2 Firespread.from.Bldg.by.Flames-(C.1)

Both of the following conditions (1) and (2) are satisfied:

(1) The incident heat flux to the exterior member of the building, such as opening, exterior wall or eaves, exposed to flames or hot gases from openings satisfies:

$$q''_m < q''_ig$$

(5.3.6.2-1)

where $q''_m$: Incident radiant heat flux to the exterior member [kW/m$^2$]

$q''_ig$: Critical ignition heat flux to the exterior member [kW/m$^2$]

(2) No crack or burn through is caused to the exterior members of the building such as an opening, an exterior wall or an eaves.
Notes for ‘Chapter 5: 5.3 Prevention of Fire Spread’

N:5.3.1 Terminology

N:5.3.2 Acceptance Criteria for Prevention of Fire Spread to Adjacent Buildings by Fire Radiation

N:5.3.2.1 Firespread.to.Bldg.by.Radiation-(P)

In the BSL, the provisions for prevention of fire spread are imposed only to the buildings in fire prevention districts and semi-fire prevention districts, which are specially designated for the safety of the areas against urban fires. This criteria are based on the same consideration as already explained in the note of ‘N: 4.3.2.2 Standard design fire conditions’, for fire safety of urban districts.

The critical radiant heat flux for the ignition of wood is 10 kW/m² or more, and those of usual window glass breaking and ignition of curtains inside of window are considered to be about the same order. In Japan, semi-fire resistive construction had been rated until recently by a standard fire test that was specific to the fire performance of exterior elements of wooden houses. The temperature-time curve was developed based on the past fire tests of conventional wooden houses. The exterior walls of such houses were hardly fire resistive so easily destroyed by fire. Accordingly, the temperature of this curve quickly reaches 840 °C at peak, but drops also quickly, resulting the duration over 800 °C is as short as about 5min.

Generally, the temperature and duration of a room fire depend on the conditions of the room and combustibles therein. As a result, the intensity and duration of the incident heat flux to a neighbor building differ from one case to another. Regarding the effects of such different heat fluxes on building elements, it is assumed that the following relation approximately holds for the ignition of a combustible:

\[ q'' t = \text{const.} \]  \hspace{1cm} (N5.3.2.1-1)

where \( q'' \) is the incident heat flux and \( t \) is the duration of heating.

According to experimental data from ISO cone ignitability tests for wood, the constant in Equation N5.3.2.1-1 may be approximated as:

\[ q'' t = 2,000 \]  \hspace{1cm} (N5.3.2.1-2)

where the \( q'' \) is in kW/m² and the time \( t \) is in minute.

For the criterion of the radiant heat flux to the surface at 0.5m in recess from the site boundary, results of fire test for rating 2nd class fire resistive construction, which used to be prescribed in the BSL, are applied. Since the temperature of 800°C, in the test, is roughly equivalent to the heat flux of 80 kW/m²,
Acceptable level of fire preventing measures of building for preventing fire spread

\[ q^{''2} t = 80^2 \times 5 = 32,000 \]  \quad (N5.3.2.1-3)

Although not explicitly stated in these criteria, note that exterior walls need to endure the fire for the prescribed time. If exterior walls are damaged by fire and openings are enlarged, it will be more difficult to satisfy the criteria due to the increase of radiant flux, \( q'' \).

N:5.3.2.2 Firespread.to.Bldg.by.Radiation-(C.)

If the fire duration in the above P-B criteria: ‘5.3.2.2 Firespread.to.Bldg.by.Radiation-(P.) is assumed to be 20 minutes, the critical radiation heat to the surface at 3m and 0.5m in recess from the site boundary are equivalent to \( q'' <10 \ [\text{kW/m}^2] \) and \( q'' <40 \ [\text{kW/m}^2] \), respectively. The \( q'' <10 \ [\text{kW/m}^2] \) is the value under which a wood never ignites, even if heated for infinite time. And the heat flux of \( q'' <40 \ [\text{kW/m}^2] \) for 20 minutes may be interpreted as the condition that a fire preventive construction, such as a mortar exterior wall or a 2nd class fire rated assembly, can manage to endure. The maximum heat flux during the fire is used in these complementary criteria, which is easier to apply but naturally more restrictive than the above P-B criteria.

Acceptable radiant heat flux to the neighbor site

In this criteria too, an exterior wall has to endure for the prescribed fire duration if the size of the opening must not to be enlarged to satisfy the criteria.
N: 5.3.3.3 Acceptance Criteria for Prevention Fire Spread to Adjacent Buildings by Window Flames

N: 5.3.3.1 Firespread to Bldg. by Flames -(C.1)

These criteria apply regardless of the conditions of a building in adjacent site because a building may be constructed if there is none at present, and an existing building can be reconstructed at any time. Therefore, the criteria for preventing to cause fire spread must be always based on the relation between a building and its site boundary.

It might seem sufficient for preventing fire spread to impose a limit to the radiant heat from windows. However, the bottom of an eaves or an opening located at higher position in exterior walls of neighbor building is hardly affected by the radiant heat from openings of the building of fire origin, yet they are apt to be exposed to window flames, or plumes. A window in an exterior wall of a building is mostly made of ordinary glasses if it locates at 3m or more in recess from its site boundary. If the windowpanes of a neighbor building break due to exposure to the flames from the window of the fire room, firebrands may invade into the neighbor building to cause fire spread. Although temperature rise is not the only mechanism of glass breaking, some experiments suggest that a conservative critical temperature rise may be 100K (120-130°C).

The temperature criterion $\Delta T_{0.5} < 400$K is the temperature for which an eaves of a fire preventive construction or a wired glass window can endure, while wood or usual glass cannot.

\[
\Delta T_{0.5} < 400 
\]

Critical temperature rise of spilled flame to the neighboring site

N: 5.3.3.2 Firespread to Bldg. by Flames -(C.2)

Since it is necessary to estimate the temperature rise of window plume, it is sometimes tedious for practitioners to apply the above criteria: 5.3.3.1 Firespread to Bldg. by Flames -(C.1). So the criteria (C.1) is translated into 5.3.3.2 Firespread to Bldg. by Flames -(C.2) in terms of dimensions of an opening and its distance from property boundary.

Based on Yokoi, approximate trajectory of window flames is given by

\[
\frac{X}{H} = 0.6 \left( \frac{Z}{H} \right)^{1/3} 
\]

where $H$ : Height of the opening [m]
\[ x : \text{Horizontal distance from the opening surface [m]} \]
\[ z : \text{Height from the upper end of the opening [m]} \]

Assuming the opening jet as a vertical plume above its fire source and using a result from McCaffrey plume, the temperature rise along the trajectory in the intermittent is:

\[
\Delta T_0 = 63 \left( \frac{z}{Q^{2/5}} \right)^{-1} \tag{N5.3.3.2-2}
\]

Meanwhile, the range of intermittent area of plume is given as follows:

\[
0.08 < \frac{z}{Q^{2/5}} < 0.2 \tag{N5.3.3.2-3}
\]

Equation N5.3.3.2-3 is roughly translated into the range of temperature rise shown as follows:

\[
315 < \Delta T_0 < 790 \tag{N5.3.3.2-4}
\]

From Equation N5.3.3.2-4, it follows that the critical temperature rise \( \Delta T = 100 \text{K} \), at 3m in recess from site boundary, is in plume region and \( \Delta T = 400 \text{K} \), at 0.5m in recess from site boundary, is in intermittent region.

Next, the total heat rate of window flames, \( Q_T \), is the sum of the enthalpy of opening jet, \( Q_V \), and the combustion heat release of excess fuel, \( Q_E \). Considering that the fire room temperature rise is 1200 [K] at most and that the mass flow rate of opening jet is roughly as \( 0.5AH^{1/2} \) [kg/sec], \( Q_V \) is estimated as

\[
Q_V = c_F m_5 \Delta T_F \approx 1 \times 0.5AH^{1/2} \times 1200 = 600AH^{1/2} \tag{N5.3.3.2-5}
\]

The mass burning rate in a fully-developed compartment fire is empirically estimated as \( 6.0AH^{1/2} \) [kg/min] (=\( 0.1AH^{1/2} \) [kg/sec]). Using 16,000 [kJ/kg] for heat of combustion of wood, the total heat release rate in compartment fire is estimated as \( 16,000 \times 0.1AH^{1/2} = 1,600AH^{1/2} \) [kW]. On the other hand, the maximum possible heat release rate within a compartment, which is controlled by the maximum inflow rate of air, is estimated as \( 3,000 \times 0.5AH^{1/2} = 1,500AH^{1/2} \) [kW]. So, the heat release rate by combustion of the excess fuel outside of the opening is estimated as

\[
Q_E \approx 1,600AH^{1/2} - 1,500AH^{1/2} = 100AH^{1/2} \tag{N5.3.3.2-6}
\]

This assumes that in-flow oxygen is completely consumed for the burning. Here, considering a certain degree of the inefficiency of the combustion in a fire room, the value is doubled for conservative estimation. Then, \( Q_T \) is estimated as

\[
Q_T \approx 600AH^{1/2} + 200AH^{1/2} = 800AH^{1/2} = 800BH^{3/2} \tag{N5.3.3.2-7}
\]

Temperature rise along plume trajectory in plume region is estimated as

\[
\Delta T_0 = 21.6 \left( \frac{Q^{2/5}}{z^{3/5}} \right) = 21.6 \left( \frac{800BH^{3/2}}{z^{3/5}} \right)^{2/15} = 1.861 \left( \frac{B}{H} \right)^{2/15} \left( \frac{z}{H} \right)^{-3/5} \tag{N5.3.3.2-8}
\]

Then, substituting \( \Delta T = 100 \text{ [K]} \) in Equation N5.3.3.2-8, and replacing \( z \) with \( x \) using Equation N5.3.3.2-1, we obtain

\[
\left( \frac{x}{H} \right)^5 = 1.4 \left( \frac{B}{H} \right)^{2/3} \tag{N5.3.3.2-9}
\]

Next, the temperature rise of plume in intermittent region is estimated as
Substituting $\Delta T=400$ [K] in Equation N5.3.2.2-10 and replacing $z$ with $x$, we obtain

$$\frac{\Delta T_0}{z} = 0.49 \left( \frac{B}{H} \right)^{2/5} \left( \frac{x}{H} \right)^{3/5}$$  \hspace{1cm} (N5.3.3.2-11)

Solving Equation N5.3.3.2-9 and N5.3.3.2-11 for $x/H$ respectively, rounding up the coefficients, and substituting the distance between an opening and location of a target surface into $x$, the formulas in the criteria are finally obtained.

However, since this criterion assumes that an opening maintains the original shape, it is necessary that the exterior walls are not damaged during the prescribed time, which is the meaning of condition (2).

N: 5.3.4 Acceptance Criteria for Prevention of Fire Spread to Adjacent Spaces

N: 5.3.4.1 Firespread to Room-(P)

N:(1)

In Japan, the ignition temperature of wood had been considered to be 260 °C for a long time, and had been the acceptance standard temperature at the unexposed surface in the standard fire resistance test. In late years, the ISO ignitability test has become popular, by which a number of test data have been accumulated for the ignition of woods. According to the test data, the critical incident heat flux of ignition of wood seems to be 12 to 15 kW/m$^2$, below which the ignition of wood is not likely to occur. This heat flux is about equivalent to the surface temperature of wood over 400 °C. However, ignition is affected by surrounding conditions. In the ISO ignitability test, the airflow around a test specimen induced by the cone heater may be strong enough to dilute the combustible volatile significantly, which may require a considerably high temperature for a wood to ignite. On the other hand, a variety of surrounding conditions can be possible for the combustibles in an adjacent room. There can be cases where airflow is so weak that volatiles are only slightly diluted. Here, the ignition temperature is assumed to be 260 °C, as is conventional, which is roughly 230 °C in terms of temperature rise, subtracting the room temperature (about 30 °C).

This critical temperature at the unexposed surface, i.e. surface temperature in the adjacent room side, applies not only to a compartment wall that contacts with a room fire, but also to an exterior wall that is exposed to a window flame or radiant heat from the room of fire origin.
A space in a building may happen to face the room of fire origin through openings with a variety of conditions, such as an opening in a compartment wall, or an atrium or a light court. Also, a space may be exposed to radiant heat through an opening in an exterior wall if flames are ejected out from the fire room.

A majority of live combustibles in a room are not remarkably different from wooden materials in terms of ignitability, so using ISO ignitability test data for woods, we have

\[ q'' t = 2,000 \] 

(N5.3.4.1-1)
as already mentioned in N:5.3.2.1. The above criterion (A) employs this as the critical incident heat flux through an opening. However, according to Eq(N5.3.4.1-1), it follows that a material eventually ignites if heated for a very long time, no matter how low the incident heat flux may be. In reality, a wood never ignites under the incident heat flux \( q'' < 10 \text{ [kW/m}^2 \text{]} \) or so, even if heated for infinite time. Considering this, the criterion (B) is added as an alternative to (A). But in some cases, the (B) can be more restrictive than (A), because the incident heat flux must not exceed the maximum even for an instance.

Incidentally, the radiant heat flux in (A) or (B) does not mean the incident heat flux to the exterior surface of an opening, but the heat flux into the interior of adjacent space, which implies that the absorption of radiation by opening materials, such as a glass pane, may be counted.

If a fire room is connected with an adjacent room through an opening, the opening may transmit flames to cause fire spread. Moreover, fire spread may be caused only by the brands transported with hot gas flow through an opening. In addition to such an opening, fire spread may be caused by a crack or a burn through caused in a compartment wall or a floor slab due to fire heating. In some cases, the verifications of these criteria may be difficult only by calculation methods, so use of appropriate fire resistance tests may be required.

N: 5.3.5 Acceptance Criteria for Prevention of Receiving Fire Spread from Adjacent Buildings by Fire Radiation

N: 5.3.5.1 Firespread from Bldg by Radiation-(P)

While the criteria: ‘5.3.2’ and ‘5.3.5’ are both relating to the prevention of fire spread by radiation between buildings, there is an essential difference: In the former, the level of radiant heat can be controlled because the building to be designed is the side of causing the radiant heat, while the fire resistive performance of the building at the receiver side cannot be controlled because it is owned by other person. Contrarily, in the latter, the building can be designed to endure whatever level of radiation, but the level of radiant heat of fire from a neighbor building cannot be controlled.

Preventing the ignition of combustibles in a building space due to incident radiation, particularly through openings, is the main object of the criterion (1), but the heat flux from an exterior wall can also be an object when the wall is made of a thermally thin material, which will re-emits significant
radiation as its temperature rises. Conservatively, the critical igniting incident heat flux for combustibles should be regarded as 10kW/m². On the other hand, the incident heat flux at near site boundary can exceed over 20kW/m² according to the fire radiation conditions mentioned in N:4.3.2.2, i.e.:

\[ q'' = \frac{250}{(2 + D)^2} \]  

(N5.3.5.1-1)

where \( D [\text{m}] \) is the distance in recess from the site boundary. As a result, it is not easy to suppress the incident heat flux into a building below 10 kW/m², even if the window is made of wired glass. However, while the design radiant heat source is assumed at right in front of the target surface, the probability that two openings, one as a target and the other as the radiant heat source, face just in front each other is thought to be rare in actual conditions, particularly when the openings are wide. Considering this, the criterion is adjusted so that the smaller the opening area, the larger incident heat can be allowed accordingly.

The criterion (2) is for the prevention of fire spread due to ignition of exterior walls, etc. The ignition here does not only concern surface materials at the exposed side but also any material constituting an exterior member, including base materials.

The last criterion (3) is for the prevention of flame penetration into inside due to deformations or cracks that may be caused to exterior members due to the exposure to fire radiation from a neighbor building.

If there is no obstacle to shield the radiation, such as a fence, the design radiant heat source condition gives the heat flux according to the equation mentioned in the above. The condition becomes stricter as the target position get closer to a site boundary, and if an opening or an exterior wall happens to be just on the site boundary (\( D = 0 \text{ m} \)), it must have the performance to endure the heat flux of \( q'' = 62.5 \text{ kW/m}^2 \).

Incidentally, the prescribed heat exposure time for fire prevention zones is determined as 1 hour, which might seem too long. However, the duration of an uncontrolled urban fire, such as a post-earthquake fire, can last over 1 hour, and the heating intensity of \( q'' = 62.5 \text{ [kW/m}^2] \) is not too demanding for exterior wall materials of buildings to cope with.

N:5.3.5.2 Firespread from Bldg. by Radiation-(C.1)

This criterion is the same as ‘5.3.5.1 Firespread from Bldg. by Radiation-(P.)’, except that the ignition criterion is changed from temperature to incident heat flux. Since the critical ignition heat flux is the minimum ignitable incident heat flux, this complimentary criterion is generally severer than the former P-B criterion, but it will be simpler in many occasions of verification because it can spare calculations of material temperature.

N:5.3.6 Acceptance Criteria for Prevention of Receiving Fire Spread from Adjacent Buildings by Window Flames

N: 5.3.6.1 Firespread from Bldg. by Flames-(P.)

The above criterion (1) concerns the ignition of exterior building members due to the exposure to flames or hot gases from openings. The temperature of hot gas window jet at the position where
the member is exposed is given as a function of the distance of the position from its site boundary. This criterion applies to every material constituting the member, such as a base material and a lining material. In principle, it is necessary to calculate the temperature rise of these members unless the temperature of the hot gas is below its ignition temperature at the position where the member is exposed.

An opening jet from the room of fire origin contains a large quantity of smoke particles as a radiation medium, so not only convective heat transfer but also radiant heat transfer should be counted in the incident heat flux. The criterion (2) concerns the prevention of flame penetration into the interior of a building, which may be caused by deformations or cracks due to exposure to window flames or hot gases.

N: 5.3.6.2 Firespread from Bldg by Flames-(C.1)

As in the case of ‘5.3.6.1 Firespread from Bldg by Flames-(P)’, this criterion employs the critical ignition heat flux instead of the ignition temperature to judge if an exterior building member, such as an opening, exterior wall or eaves, is acceptably tolerant against the exposure to window flames. Like in the above, not only convective heat transfer but also the radiant heat transfer has to be counted in the incident heat flux.

While the verification using the temperature criterion needs to estimate the incident heat flux from flames or hot gas first, and then to calculate the temperature of a material, the verification based on the incident heat flux does not need temperature calculation, so the verification procedure is much simpler. However, the critical ignition heat flux is such that a wood never ignites even if heated for infinite time, so it may turn out to be impractically conservative in some cases. For example, while one of the effective measures to prevent the ignition of a combustible exterior wall is to cover it with incombustible boards, it is thought to be too difficult to evaluate their effect properly by this criterion.
5.4 Assurance of Fire Fighting Activity

5.4.1 Terminology

5.4.1.1 Firefighting activity
Operations conducted by fire brigades for search and rescue of occupants left behind in a building on fire and fire extinguishments, etc.

5.4.1.2 Space for fire fighting activity
Space expected to be used by brigades as a fire fighting base or as an access route to a base

5.4.1.3 Fire room side space
Space located closer to the fire room relative to a partition wall or an opening concerned, in a smoke spread route from the fire room

5.4.1.4 Out door Space
Space at the outside of exterior walls or openings of a building, which is open to air and not covered under a ceiling

5.4.1.5 Duration of fire fighting activity
Duration while fire brigades stay in a 'space for fire fighting activity'

5.4.2 Acceptance Criteria for Safety of Fire Brigades from Smoke in Building

An indoor space for fire fighting activity of a building that satisfies whichever of the following criteria: 5.4.2.1 – 5.4.2.4, during the prescribed time for fire fighting is deemed to be at the acceptable level with respect to the safety of fire brigades from smoke in a building.

5.4.2.1 Firefight.Smoke.Indoor-(P.)
The smoke to which any fire fighter is exposed in the space satisfies:

\[ \int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1.0 \times 10^5 \]  \hspace{1cm} (5.4.2.1-1)

where
- \(T\) : Temperature rise of the smoke to which the fire fighter is exposed to [K]
- \(t_1\) : Time at which the fire fighter begins to be exposed to the smoke [sec.]
- \(t_2\) : Time at which the fire fighter ceases to be exposed to a smoke [sec.]

In the above formula, a fire fighter in the space is determined to be exposed to smoke by either of the following conditions (a) or (b):

(a). Temperature of smoke

\[ \Delta T > 0 \]  \hspace{1cm} (5.4.2.1-2)
where \( \Delta T \): Temperature rise of the smoke in the space [K]

(b). Height of smoke layer

\[ S < 1.6 + 0.1H \]  

(5.4.2.1-3)

where \( S \): Height of the smoke layer interface from the floor of the fire fighter [m]  
\( H \): Average ceiling height of the space from the floor of the fire fighter [m]

5.4.2.2 Firefight.Smoke.Indoor-(C.1)

The smoke to which any fire fighter is exposed in the space satisfies:

\[ (\Delta T_{\text{max}})^2(t_2 - t_1) < 1.0 \times 10^5 \]  

(5.4.2.2-1)

where \( \Delta T_{\text{max}} \): Maximum temperature rise of the smoke to which the fire fighter is exposed [K]  
\( t_1 \): Time at which the fire fighter begins to be exposed to the smoke [sec.]  
\( t_2 \): Time at which the fire fighter ceases to be exposed to a smoke [sec.]

In the above formula, a fire fighter in the space is determined to be exposed to smoke by either of the following conditions (a) or (b):

(a) Temperature of the smoke satisfies:

\[ \Delta T > 0 \]  

(5.4.2.2-2)

where \( \Delta T \): Temperature rise of the smoke in the space [K]

(b) Height of the smoke layer satisfies

\[ S < 1.6 + 0.1H \]  

(5.4.2.2-3)

where \( S \): Height of the smoke layer interface from the floor of the fire fighter [m]  
\( H \): Average ceiling height of the space from the floor of the fire fighter [m]

5.4.2.3 Firefight.Smoke.Indoor-(C.2)

The smoke layer in the space concerned satisfies:

\[ S > 1.6 + 0.1H \]  

(5.4.2.3-1)

where \( S \): Height of the smoke layer interface from the floor of the fire fighter [m]  
\( H \): Average ceiling height of the space from the floor of the fire fighter [m]

5.4.2.4 Firefight.Smoke.Indoor-(C.3)

Either of the following conditions (1) - (2) is satisfied at any of the partitions in every smoke propagation route from fire room to the space for fire fighting concerned:

(1) The pressure difference at openings or gaps in the partition concerned satisfies:

\[ \Delta P(z) > 0 \quad (h_1 < z < h_2) \]  

(5.4.2.4-1)
where \( \Delta P(z) \): Pressure difference of the evacuation side space relative to fire room side space [Pa]
\( z \): Height [m]
\( h_1 \): Lower end height of an opening or a gap in the partition concerned [m]
\( h_2 \): Upper end height of an opening or a gap in the partition concerned [m]

(2) The smoke layer height in a fire room side space satisfies:
\[
S > h_2 + 0.1(H - h_2)
\]

where \( S \): Height of the smoke layer interface from the floor in the fire room side space [m]
\( H \): Average ceiling height of the fire room side space [m]
\( h_2 \): Uppermost end height of the openings and gaps on the partition concerned [m]

5.4.3 Acceptance Criteria for Safety of Fire Brigades from Smoke at Outdoor

An outdoor space of a building that satisfies whichever of the following criteria: 5.4.3.1 - 5.4.3.3, during the prescribed time for fire fighting is deemed to be at the acceptable level with respect to the safety of fire brigades from smoke in a building.

5.4.3.1 Firefight.Smoke.Outdoor-(P.)

The smoke to which any fire fighter is exposed during the fire fighting in the space satisfies:
\[
\int_{t_1}^{t_2} (\Delta T)^2 \, dt < 1.0 \times 10^5
\]

where \( \Delta T \): Temperature rise of the smoke to which the fire fighter is exposed [K]
\( t_1 \): Time when the fire fighter begins to be exposed to the smoke [sec.]
\( t_2 \): Time when the fire fighter ceases to be exposed to the smoke [sec.]

5.4.3.2 Firefight.Smoke.Outdoor-(C.1)

The smoke to which anyone of fire fighters is exposed during the fire fighting in the space satisfies:
\[
(\Delta T_{\text{max}})^2(t_2 - t_1) < 1.0 \times 10^5
\]

where \( \Delta T_{\text{max}} \): Maximum temperature rise of the smoke to which the fire fighter is exposed [K]
\( t_1 \): Time when the fire fighter begins to be exposed to the smoke [sec.]
\( t_2 \): Time when the fire fighter ceases to be exposed to the smoke [sec.]

5.4.3.3 Firefight.Smoke.Outdoor-(C.2)

The smoke to which any the fire fighter is exposed during the fire fighting in the space satisfies all the following conditions (1) - (3):

(1) Whichever of the following conditions (i) - (iii) is satisfied as to the location of the space for fire fighting relative to any opening that may eject smoke in the event of fire,
(i) Height from the sill of the opening
\[ z < 0 \tag{5.4.3.3-1} \]
where \( z \) : Height from the lower end of the opening [m]

(ii) Horizontal distance perpendicular to the opening surface
\[ \frac{x}{H} > 0.6 \left( \frac{z}{H} \right)^{0.3} + 0.3 \left( \frac{z}{H} \right) \tag{5.4.3.3-2} \]
where \( H \) : Height of the opening [m]
\( x \) : Horizontal distance from the opening that is perpendicular to its surface [m]
\( z \) : Height from the sill of the opening [m]

(iii) Horizontal distance parallel to the opening surface satisfies:
\[ \frac{y}{H} > 0.3 \left( \frac{z}{H} \right) \tag{5.4.3.3-3} \]
where \( H \) : Height of the opening [m]
\( y \) : Horizontal distance from the side of the opening that is parallel to its surface [m]
\( z \) : Height from the sill of the opening [m]

(2) There is no particular eaves or balcony that disturbs the free rise of the opening spill plume.

(3) No cracks or burn through that may allow flames to transmit is caused in the exterior walls of the fire compartment during the fully developed fire.

### 5.4.4 Acceptance Criteria for Safety of Fire Brigades from Radiant Heat

A space that satisfies either of the following criteria: 5.4.4.1 - 5.4.4.2 during the prescribed time for fire fighting is deemed to be acceptable with respect to the safety of fire brigades from radiant heat.

#### 5.4.4.1 Firefight.Radiation-(P.)

The radiant heat to which any fire fighter is exposed during the fire fighting in the space satisfies:
\[ \int_{t_1}^{t_2} I^2 dt < 2.5 \times 10^3 \tag{5.4.4.1-1} \]
where
\[
I = \begin{cases} 
q'' - 0.5 & (q'' > 0.5) \\
0 & (q'' \leq 0.5) 
\end{cases} \tag{5.4.4.1-2}
\]
where \( q'' \) : Incident heat flux to the fire fighter [kW/m²]
\( t_1 \) : Time at which the fire fighter begins to be exposed to the radiant heat [sec]
\( t_2 \) : Time at which the fire fighter ceases to be exposed to the radiant heat [s]
5.4.4.2 Firefight.Radiation-(C.1)

The radiant heat to which any fire fighter is exposed during the fire fighting in the space satisfies:

\[ I^2(t_2 - t_1) < 2.5 \times 10^3 \]  

(5.4.4.2-1)

where

\[ I = \begin{cases} 
q_{\text{max}}^* - 0.5 & (q^* > 0.5) \\
0 & (q^* \leq 0.5) 
\end{cases} \]  

(5.4.4.2-2)

where  \( q'' \): Maximum incident heat flux to the fire fighter [kW/m²]

\( t_1 \): Time at which the fire fighter begins to be exposed to the radiant heat [sec]

\( t_2 \): Time at which the fire fighter ceases to be exposed to the radiant heat [sec]
Notes for ‘Chapter 5: 5.4 Assurance of Firefighting Activity’

N: 5.4.1 Terminology

This criterion concerns the safety from smoke of fire brigades in spaces that are important for fire service operations, such as a fire fighting base and the route from the outdoors to the base. The 'space for fire fighting' means both of the fire fighting base, such as a lobby of a staircase or a lobby of a fire elevator, and an access route to a base, such as a stairs or a fire elevator.

Definition of 'fire side space' is introduced because it is often necessary to clarify which side of a partition or an opening on smoke propagation route smoke or pressure condition is discussed.

N: 5.4.2 Acceptance Criteria for Safety of Fire Brigades from Smoke in Building.

N: 5.4.2.1 Firefight.Smoke.Indoor-(P.)

The concept of this criterion is basically the same as ‘5.1.2.1 Evac.Smoke.Indoor-(P.)’, for the safety from smoke of evacuee in a building, except that the critical value is eased to a certain degree, considering that fire brigades are trained specially to cope with the danger of fire, that they prepare for fire fighting and that it is not easy to ensure a high level of safety for the environment of fire fighters, because of the sever fire conditions envisaged during fire fighting activities.

As to the duration of fire fighting in this criterion, the \((t_1-t_2)\) can be taken as the duration of stay in the case of a fire fighting base and the time to pass through in the case of the access route to a base such as a staircase.

N: 5.4.2.2 Firefight.Smoke.Indoor-(C.1)

This criterion is similar to the complimentary criterion: ‘5.1.2.2 Evac.Smoke.Indoor-(C.1)’, for the safety of evacuees in a building except that the critical value is somewhat eased for the same reason as above.

N: 5.4.2.3 Firefight.Smoke.Indoor-(C.2)

This criterion is similar to the complimentary criterion '5.1.2.3 Evac.Smoke.Indoor-(C.2)', for the safety of evacuees in a building. This indicates the condition that a fire fighter is not exposed to smoke. In a space used for a base for fire fighting such as a lobby of staircase, it will be possible to comply with this condition by providing an adequate smoke exhausting system.

N: 5.4.2.4 Firefight.Smoke.Indoor-(C.3)

This criterion is similar to the complimentary criterion '5.1.2.4 Evac.Smoke.Indoor-(C.3)', for the safety of evacuees in a building.

N: 5.4.3 Acceptable Criteria for Safety of Fire Brigades from Smoke at Outdoor

N: 5.4.3.1 Firefight.Smoke.Indoor-(P.)

The concept of this criterion is basically the same as ‘5.1.2.1 Evac.Smoke.Indoor-(P.)’ for the safety from smoke of evacuee at outdoor space of a building, except that the critical value is eased considering the characteristics of fire brigade and fire fighting activity.
N: 5.4.3.2 Firefight.Smoke.Outdoor-(C.1)

The concept of this criterion is basically the same as supplementary criterion ‘5.1.2.1 Evac.Smoke.Indoor-(C.1)’ for the safety from smoke of an evacuee at outdoor space of a building, except that the critical value is eased considering the characteristics of fire brigade and fire fighting.

N: 5.4.3.3 Firefight.Smoke.Outdoor-(C.2)

The concept of this criterion is basically the same as ‘5.1.2.3 Evac.Smoke.Indoor-(C.2)’, for the safety from smoke of an evacuee at outdoor space of a building.

N: 5.4.4 Acceptance Criteria for Safety of Fire Brigades from Radiation

N: 5.4.4.1 Firefight.Radiation-(P.)

This criterion is generally the same as ‘5.1.3.1 Evac.Radiation-(P.)’, for the safety from radiation of evacuee, except that the critical value is eased considering the characteristics of fire brigade and fire fighting.

N: 5.4.4.2 Firefight.Radiation-(C.1)

This criterion is the same as ‘5.1.3.2 Evac.Radiation-(C.1)’ for the safety from radiation of a fire fighter, except that the critical value eased considering the characteristics of fire brigades and fire fighting.

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