Tenability In Building Fires: Limits And Design Criteria

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In the Winter Edition of *Fire Australia*, Barry Lee outlined some aspects of tenability in building fires. He has correctly pointed out that there is not a single set of values for tenability criteria which is universally accepted. This includes the International Fire Engineering Guidelines which does not provide specific guidance on setting tenability criteria for fire safety design.

In performance-based design and analysis of buildings for fire safety, appropriate tenability criteria must be set to ensure that the occupants are not exposed to untenable conditions. This paper further discusses tenability in building fires and outlines the current design approaches and the associated tenability criteria for assessing fire safety of buildings.

TENABILITY LIMITS

In a building fire, the main hazards to the occupants are exposures to the heat and toxic gases from the fire (see Figure 1). In *Assessment of Hazards to Occupants from Smoke, Toxic Gases and Heat*, Purser gives a comprehensive review of the hazards and tenability limits for exposures to heat and toxic gases. Some aspects of these are summarised below.

Exposure to Heat

There are three basic ways in which heat exposure may lead to life threat:

- heat stroke (hyperthermia)
- skin pain or burns
- respiratory tract burns.

The causes and tenability limits for heat exposure are summarised in Table 1.

The limits in Table 1 are generally determined for exposure to naked skin. The limits can be significantly higher with the protection of clothing.

Table 1: Heat Exposure and Tenability Limits

EVENT	CAUSE	EXPOSURE LEVEL
Heat stroke (hyperthermia)	Prolonged exposure (more than 15 minutes) to heated environments	60°C - 120°C
Skin pain or burns	Exposure to convected heat (dry air <10% water)	> 120°C
	Exposure to convected heat (water-saturated air)	> 60°C
	Exposure to radiant heat	> 2.5 kW/m2
	Exposure to conducted heat (contact with hot metal surface)	> 60°C
Respiratory tract burns	(same as for skin burns)	(same as for skin burns)

For example, field tests have shown that a radiant heat flux of 5.0 kW/m2 is tolerable without causing skin pain or burns with the protection of light clothing.

Exposure to Toxic Gases

Exposure to toxic gases (asphyxiants) is the main cause of incapacitation (loss of consciousness) and death in building fires. The severity depends on the concentration and duration of the exposure. Tenability limits for exposures to common asphyxiants produced from fires are summarised in Table 2.

Smoke Obscuration

Smoke obscuration leads to a reduction in visibility, which is not directly life-threatening. However, it may reduce the walking speed of individuals, thereby increasing the exposure time to heat and toxic gases. Combustion gases that cause irritation to the eyes may have a similar effect to reduced visibility. These include acid gases (HF, HCl, HBr, SO_2, NO_x) and organic irritant gases (acrolein, formaldehyde, crotonaldehyde).

TENABILITY CRITERIA

In the design and analysis of buildings for fire safety, criteria must be set to ensure that the occupants are not exposed to conditions that exceed the tenability limits. Generally, these are set based on the following assumptions:

- Heat exposure is primary due to convection and radiation (exposure to conducted heat is ignored), and the upper limit is the skin burn threshold
- Respiratory tract burns occur at the same limits as skin burns and no separate criterion is required
- The air environment during the fire is dry (<10 percent water)
- The primary asphysiants are CO and HCH, and the upper limits are the incapacitation thresholds
- O_2 concentrations generally do not fall below 12 percent and consideration of low O_2 is not required. The narcotic effect of CO_2 is also not significant at the concentrations experienced in fire atmospheres.

The appropriate criteria will depend on the design approach to be adopted with respect to smoke exposure. Three common approaches, in order of increasing rigour, are:

- no exposure
- short exposure (less than 15 minutes)
- general exposure (up to 30 minutes).

No Exposure

This is the simplest and the most conservative approach which assumes that the occupants are not directly exposed to the smoke from the fire. This is achieved by maintaining the smoke layer above the head height of the occupants.

The smoke hazard management design prescribed by the Building Code of Australia (BCA) is based on this approach, which requires the smoke layer to be maintained not less than 2 metres above the floor level.

In this approach, convected heat and toxic gas exposures can be ignored. However, the occupants can still be exposed to radiant heat from the hot smoke layer above. It is noted that the BCA does not specify any limit for radiant heat. However, criterion for radiant heat is still applicable to ensure safety of the occupants.

The upper limit commonly adopted for radiant heat is 2.5 KW/m2 (see Figure 2). For small enclosures, this limit may be reached when the hot layer temperature rises above 200°C.

Short Exposure

For situations where the smoke layer cannot be maintained above head height, criteria must be set to ensure that the occupants are not excessively exposed to the smoke while they move away from the fire to a place of safety.

Simple tenability criteria can be set for these situations by assuming and ensuring a relatively short duration of exposure (say, up to 15 minutes). An example of a set of criteria used in this approach is shown in Figure 3.

These criteria are generally conservative, since the occupants are unlikely to be exposed to the limiting environments for the entire duration. Further conservatism is introduced by measuring the exposures at a level above head height (see Figure 3). It is often argued that they may be more appropriately measured within the breathing zone, which can be taken at any height between 1.5m and 2.0m.

A limit of 100°C for convected heat is commonly used in Australia, as this was suggested in the first version of Fire Engineering Guidelines. Overseas, various limits ranging from 60°C -120°C are used depending on the assumed duration and conditions of exposure.

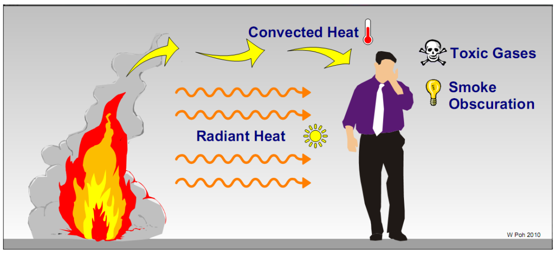

Figure 1 Exposure in Building Fire

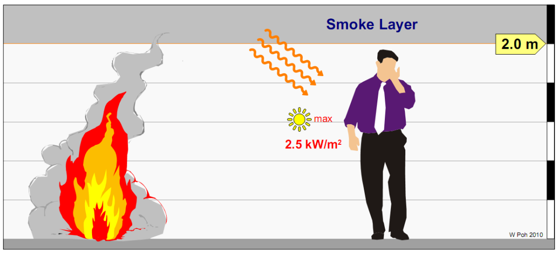

Figure 2 Typical Tenability Criteria for No Exposure

Visibility limit is usually set at 5m and 10m for small and large enclosures, respectively. However, as discussed earlier, a reduction in visibility is not directly life threatening. It may reduce the walking speed of individuals, thereby increasing the exposure time to heat and toxic gases.

Australasian Fire Authorities Council (AFAC) has also adopted criteria for firefighters safety limits using a similar approach for short exposure periods. The criteria for firefighters are generally more severe given that they are better equipped with protective gear (see Table 3). The above limits were developed based on comfort levels reported during some tests conducted in 1994. The radiant heat limit of 1.0 kW/m2 for routine firefighting condition was nominally set. Review of more recent test results indicates that a higher limit may be more appropriate, since it is lower than the heat flux received from sun bathing in the tropics, which is estimated to be 1.1 kW/m2.

Figure 4 shows the AFAC criteria for firefighters for exposure of up to 10 minutes.

General Exposure

With the availability of advanced analyses methods, a more rigorous assessment of heat and toxic gas exposure may be carried using Fractional Effective Dose (FED) calculations. This method takes into account the variation of the exposure environments with time and the combined effects of the exposures to various effects of the fire. It is suitable for exposure periods of up to 30 minutes.

The FED method involves the determination of the exposure doses at each regular discrete time increment and summing the exposure doses to get the cumulative dosage for the total period of exposure. The doses are calculated as a fraction of incapacitation dosage, and hence the maximum value of FED = 1.0 represents the state of incapacitation. Heat exposure is calculated as an FED, taking into account the combined effects of convected and radiant heat. Toxic gas exposure is calculated as a separate FED, taking into account the combined effects of the relevant gases. The effects of varying O_2 and CO_2 may also be included in the calculation.

Using this method, tenability criteria for heat and toxic gas exposures are usually set at FED = 1.0 and FED = 0.3, respectively (see Figure 5).

The FEDs are often measured at a height of 2.0m, although they may be taken at any height between 1.5m and 2.0m, as discussed in the previous section of this paper.

The same approach can also be used to determine the fractional effective concentration (FEC) of combustion gases that cause irritation to the eyes and respiratory tracts, including acid gases (HF, HCl, HBr, SO_2, NO_x) and organic irritant gases (acrolein, formaldehyde, crotonaldehyde).

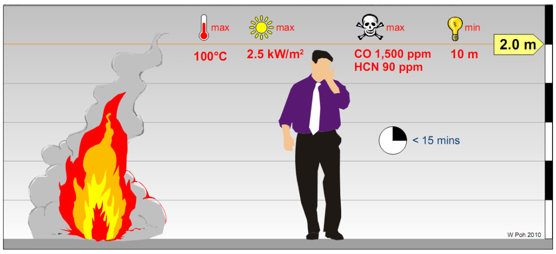

Figure 3 Example of a Set of Tenability Criteria for Short Exposure

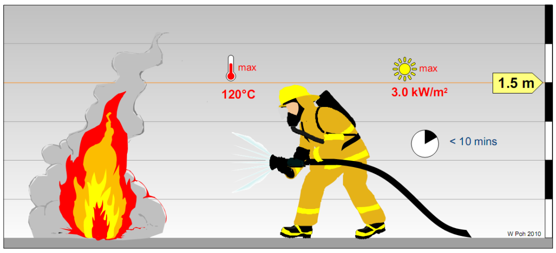

Figure 4 AFAC criteria for firefighters for exposure of up to 10 minutes.

CONCLUSION

In the design of buildings for fire safety, tenability limits in building fires must be understood. In this paper, fire hazards and their associated tenability limits have been discussed. Common design approaches and the basis of their associated criteria have been outlined.

Currently, there is not a single set of values for tenability criteria which is universally accepted. Fire safety professions, regulators and the authorities must work together to agree and adopt a consistent approach and criteria for design of buildings for fire safety.

Table 2: Tenability Limits for Exposures to Asphyxiants

	5 MIN EXPOSURE		30 MIN EXPOSURE	
	INCAPACITATION	DEATH	INCAPACITATION	DEATH
Carbon Monoxide CO	6,000 ppm	12,000 ppm	1,400 ppm	2,500 ppm
Hydrogen Cyanide CHN	150 ppm	250 ppm	90 ppm	170 ppm
Low Oxygen O2 (Hypoxia)	<13%	<5%	<12%	<7%
Carbon Dioxide CO2	>7%	>10%	>6%	>9%

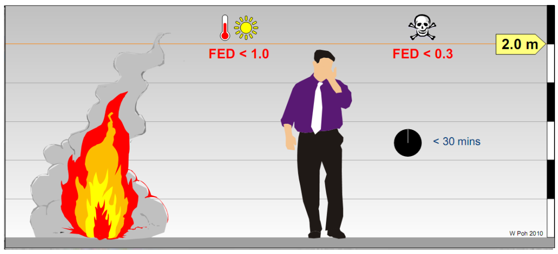

Figure 5 Typical Tenability Criteria using FED approach

Table 3: Tenability Limits for Fire Fighters Adopted by AFAC

	ROUTINE CONDITION	HAZARDOUS CONDITION	EXTREME CONDITION	CRITICAL CONDITION
Maximum Time	25 minutes	10 minutes	1 minute	< 1 minute
Maximum Air Temperature	100°C	120°C	160°C	> 235°C
Maximum Radiation	1kW/m2	3kW/m2	4 - 4.5kW/m2	> 10kW/m2