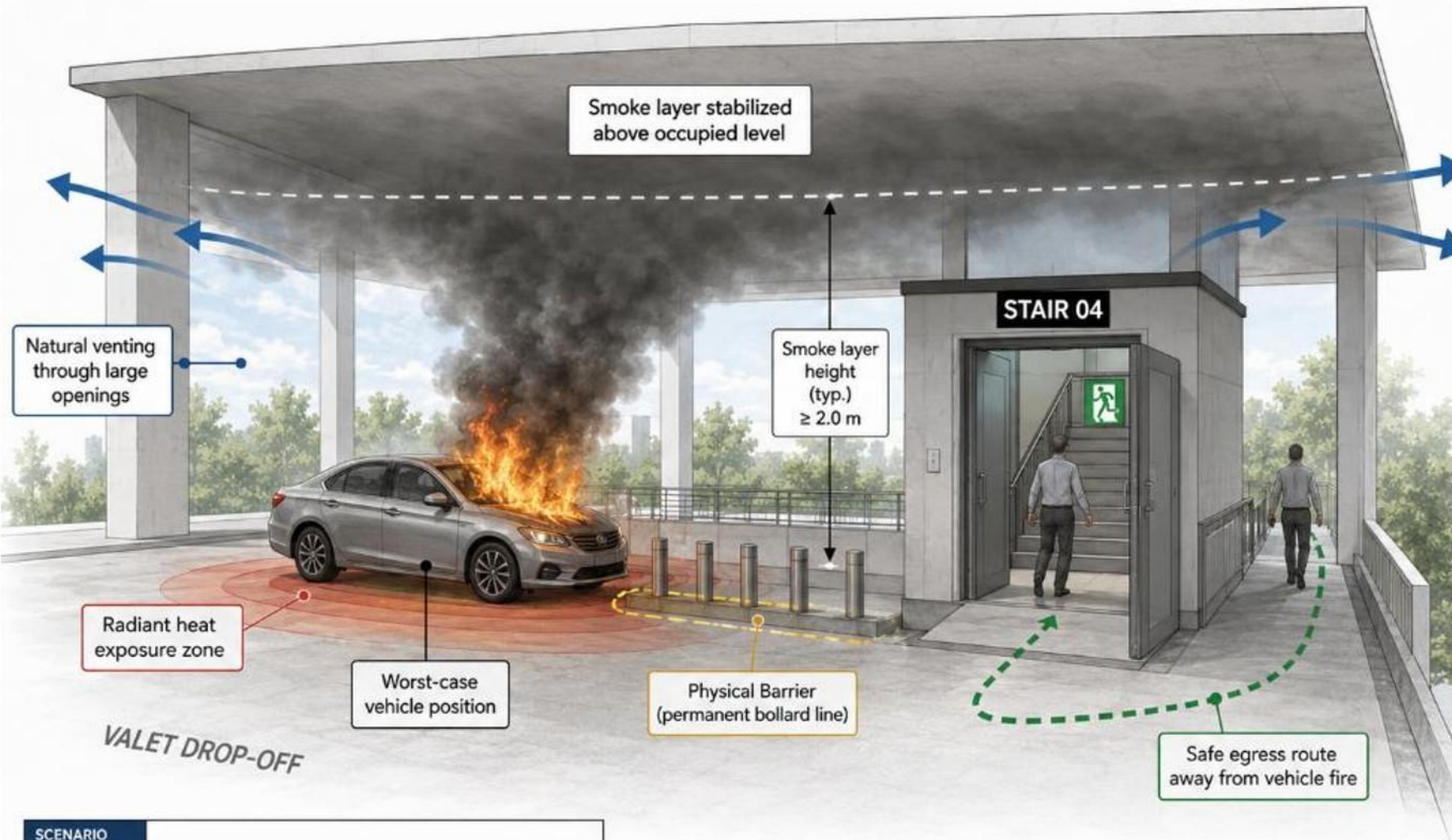


Exit Stair 04 Valet Drop-Off Smoke Accumulation and Exit Stair 04 Termination

11th June 2026



SCENARIO	
Fire	Passenger vehicle fire in valet drop-off (worst-case position)
Condition	Covered area with large open sides
Smoke Control	Natural venting maintains smoke layer high above occupied level
Protection	Physical barrier prevents vehicle encroachment to stair discharge
Egress	Stair 04 discharge provides safe egress away from fire

KEY OUTCOMES	
✓	Smoke layer stabilized high above occupied zone
✓	Large openings ventilate smoke effectively
✓	Stair 04 remains tenable for egress

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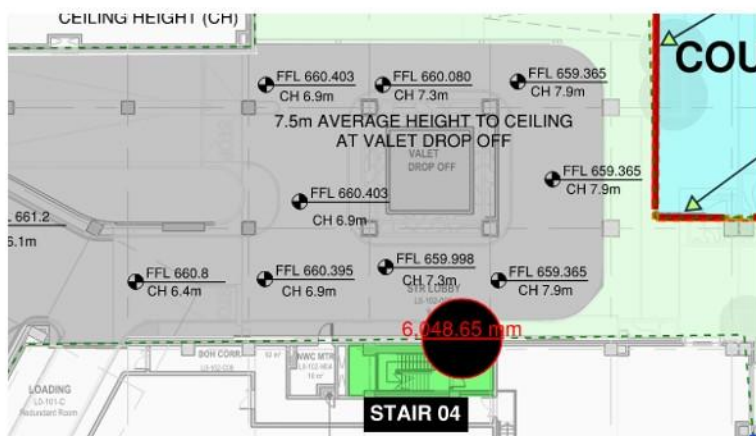
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1. Executive summary

The smoke calculation is like a filling-and-draining problem. The car fire produces smoke. The large openings drain smoke out by buoyancy. At the normal occupant heights of 2.5 m, 2.0 m and 1.8 m, the available opening capacity is many times larger than the smoke production from the vehicle fire. The smoke layer therefore stabilises high above people instead of descending into the exit route.

2. Scope and issue for determination

This report calculates the stair 04 valet drop-off scenario on the basis that a permanent physical barrier will prevent any vehicle from stopping, parking, queuing, idling, or failing within 3.0 m of the stair 04 exit door. The vehicle fire is therefore moved from the worst-case “at-door” condition to the nearest physically possible vehicle position, taken as the boundary of the 3.0 m exclusion zone as shown below.

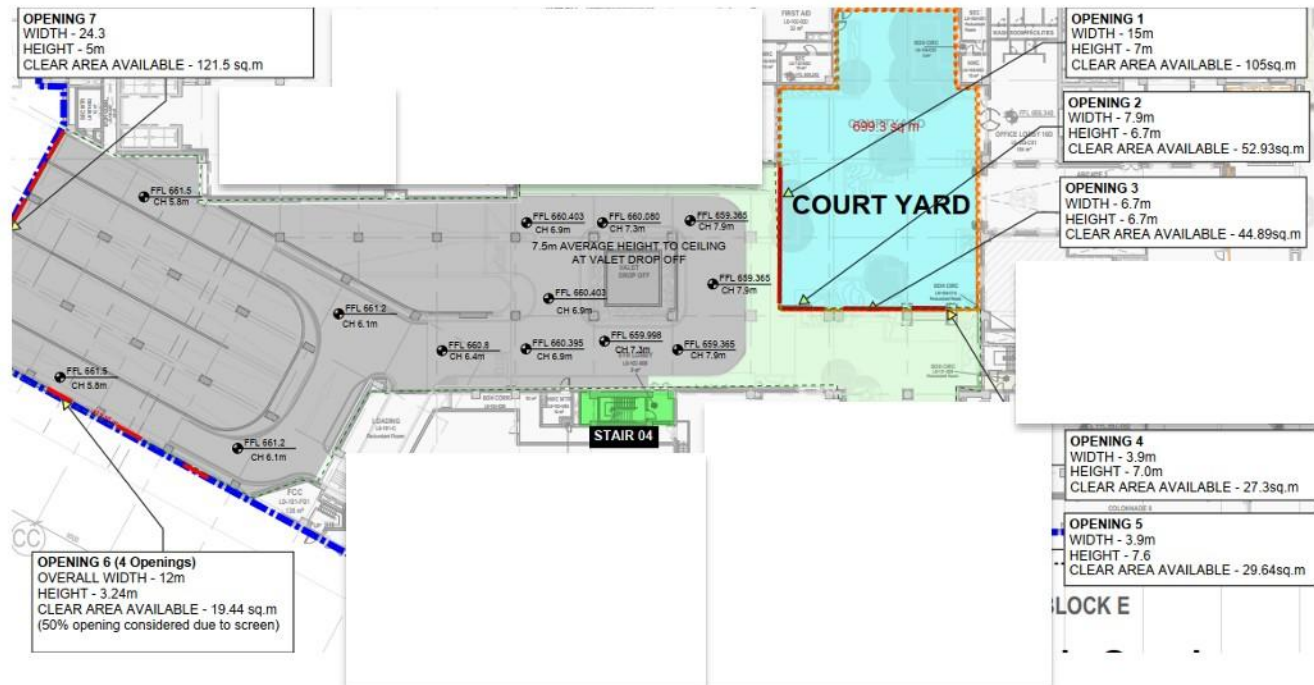


The assessment uses the detailed opening schedule shown on the floor plan file name “ABC”. The report treats the valet drop-off as a naturally vented covered volume.

The problem is assessed in two stages:

- No-vent screen: pretend the openings do not exist. This gives a conservative “how bad could smoke descent be if the space behaved like a closed reservoir?” check.
- Actual open-sided condition: credit only the parts of the openings above the smoke layer. If buoyant natural venting removes more smoke than the fire plume supplies, the layer cannot keep descending and will stabilize high above the occupied zone.

3. Project geometry used in the calculation



Layout showing valet drop-off zone, Stair 04, courtyard and available opening areas.

Table 1. Opening areas adopted from the ground floor plan

Opening	Width (m)	Height (m)	Clear area (m ²)
Opening 1 - courtyard	15.0	7.00	105.00
Opening 2 - courtyard	7.9	6.70	52.93
Opening 3 - courtyard	6.7	6.70	44.89
Opening 4 - courtyard	3.9	7.00	27.30
Opening 5 - south public way	3.9	7.60	29.64
Opening 6 - south-west elevation, screened	12.0	3.24	19.44
Opening 7 - west public road	24.3	5.00	121.50
Total opening area			400.70

Table 2. Adopted geometry and protection assumptions

Parameter	Adopted value	Reason / source
Average ceiling height at valet drop-off	7.5 m	Read from the plan
Open-to-sky courtyard	699.3 m ²	Read from the plan
Effective smoke reservoir, conservative	700 m ²	Represents the valet drop-off smoke reservoir.
Effective smoke reservoir, extended	2,275 m ²	Sensitivity representing broader smoke spread through the open valet drop-off volume.
Physical vehicle exclusion	3.0 m minimum	Nearest car envelope cannot be closer than 3.0 m from Stair 04 door and corresponding designated exit access path.
Sprinkler protection	Present	Credited as controlling growth, not instant extinguishment.

4. Acceptance basis

The acceptance question is whether stair 04 can discharge fronting the valet drop off zone without occupants being forced into a smoke-logged layer, direct vehicle-fire plume, or local untenable radiant-heat condition.

This report checks whether the smoke interface descends to 2.5 m, 2.0 m or 1.8 m above floor. The 2.0 m and 1.8 m levels are treated as the principal standing occupant exposure heights. For direct radiation, a 2.5 kW/m² conservative tenability threshold is used as the strict screen while a higher short-duration screen is also shown to distinguish moving occupants from occupants forced to wait near the fire¹.

This report is sufficient to determine whether the 3.0 m physical exclusion materially established a safe condition.

5. Design fires

The recalculation uses three fire severities. A 2 MW case represents a sprinkler-controlled or early controlled vehicle fire. A 5 MW case represents a developed single saloon car fire. An 8 MW case is used as a severe sensitivity for modern passenger-vehicle fire severity.

Table 3. Design fire cases used

Case	Total HRR, Q (MW)	Convective HRR, Q _c (MW)	Purpose
Sprinkler-controlled vehicle fire	2.0	1.4	Post-activation / controlled sensitivity
Developed saloon car fire	5.0	3.5	Baseline developed vehicle fire
Severe vehicle fire sensitivity	8.0	5.6	Conservative modern-vehicle sensitivity

NIST Vehicle 1, a 2015 ICE compact sedan, recorded a peak heat release rate of 5,039 kW and time to peak of 17.97 min. NIST Vehicle 3, a 2010 hybrid sedan with the lithium-ion battery removed and gasoline in the tank, recorded a peak heat release rate of 8,527 kW and time to peak of 11.95 min. These values justify the 5 MW and 8 MW design-fire bracket used in this report².

6. Governing equations

Steady smoke-filling screen from the Handbook of Smoke Control Engineering

For a quick conservative no-vent screen, the report uses the steady smoke-filling equation from the Handbook of Smoke Control Engineering. The equation estimates the height of the first indication of smoke and ignores the permanent openings. That makes it suitable as a conservative demonstration.

$$\frac{z}{H} = 1.11 - 0.28 \ln \left(\frac{t Q^{1/3} H^{-4/3}}{A/H^2} \right) \text{ for SI} \quad (15.1)$$

Equation 1. Steady smoke-filling correlation, SI form³.

¹ D A Purser and J L McAllister, 'Assessment of Hazards to Occupants from Smoke, Toxic Gases, and Heat' in M J Hurley (ed), SFPE Handbook of Fire Protection Engineering (5th edn, Springer 2016) 2417. See also Society of Fire Protection Engineers, SFPE Guide to Human Behavior in Fire (2nd edn, Springer 2019) 64-66.

² National Institute of Standards and Technology, 'Vehicle1' (NIST Fire Calorimetry Database, last updated 3 April 2025) <<https://www.nist.gov/el/fcd/design-fires-vehicles-pine-straw-bed/vehicle1>> accessed 9 June 2026; National Institute of Standards and Technology, 'Vehicle3' (NIST Fire Calorimetry Database, last updated 3 April 2025) <<https://www.nist.gov/el/fcd/design-fires-vehicles-pine-straw-bed/vehicle3>> accessed 9 June 2026.

³ J H Klote and others, *Handbook of Smoke Control Engineering* (ASHRAE 2012) 323, Eq 15.1; J A Milke, 'Smoke Control by Mechanical Exhaust or Natural Venting' in M J Hurley (ed), *SFPE Handbook of Fire Protection Engineering* (5th edn, Springer 2016) 1832, Eq 51.13.

$$t = \frac{A H^{4/3}}{H^2 Q^{1/3}} \exp\left[\frac{1}{0.28}\left(1.11 - \frac{z}{H}\right)\right] \text{ for SI} \quad (15.2)$$

Equation 2. Time-to-height form of the steady smoke-filling correlation⁴.

provided that A is a constant with respect to z ,

$$0.2 \leq \frac{z}{H} \leq 1.0, \text{ and } 0.9 \leq \frac{A}{H^2} \leq 14,$$

where

- z = distance above base of fire to first indication of smoke, ft (m),
- H = ceiling height above base of the fire, ft (m),
- t = time, s,
- Q = heat release rate, Btu/s (kW),
- A = cross-sectional area of atrium, ft² (m²).

Equation 3. Stated applicability range for the steady smoke-filling equations⁵.

Derivation of Equation 2 from Equation 1: let

- $X = (t Q^{1/3} H^{-4/3}) / (A/H^2)$.
- Equation 1 becomes $z/H = 1.11 - 0.28 \ln(X)$.
- Move the logarithm term: $\ln(X) = (1.11 - z/H)/0.28$.
- Remove the logarithm: $X = \exp[(1.11 - z/H)/0.28]$.
- Substitute back for X and solve for t . This gives Equation 2.

Convective heat release rate

The plume and smoke-layer equations use the convective portion of the fire heat release rate, because buoyant plume flow is driven mainly by heat transferred to the surrounding air. There the convective heat release rate is assumed to be 70% of the total heat release rate⁶.

$$\dot{Q}_c = 0.7 \dot{Q}$$

Equation 4. Convective heat release rate used in the smoke calculations⁷.

SFPE no-vent smoke-layer descent equation

⁴ Klote and others, *Handbook of Smoke Control Engineering* (ASHRAE 2012) 323, Eq 15.2.

⁵ Klote and others, *Handbook of Smoke Control Engineering* (ASHRAE 2012) 323.

⁶ J A Milke, 'Smoke Control by Mechanical Exhaust or Natural Venting' in M J Hurley (ed), *SFPE Handbook of Fire Protection Engineering* (5th edn, Springer 2016) 1834- Ranges between 0.7 to 0.8.

⁷ Milke, 'Smoke Control by Mechanical Exhaust or Natural Venting' in Hurley (ed), *SFPE Handbook* (5th edn, Springer 2016) 1833.

The SFPE Handbook steady-fire smoke-layer position equation is used as a second conservative no-vent calculation. It assumes the smoke layer forms immediately and ignores the 400.70 m² clear opening area.

$$\frac{z}{H} = \left[1 + \frac{2k_v t \dot{Q}^{1/3}}{3(A/H^2)H^{4/3}} \right]^{-3/2} \quad (51.22)$$

Equation 5. SFPE steady-fire smoke-layer descent equation used for the no-vent check⁸.

$$t = \frac{3A}{2k_v \dot{Q}_c^{1/3}} \left[z_L^{-2/3} - H^{-2/3} \right]$$

Equation 6. Rearranged time-to-height expression used to calculate smoke descent times⁹.

Derivation of Equation 6 from Equation 5:

- Raise both sides of Equation 5 to the power ^{-2/3}.
- $(z_L/H)^{-2/3} = 1 + [2 k_v t \dot{Q}_c^{1/3}]/[3(A/H^2)H^{4/3}]$.
- Subtract 1 from both sides and isolate t.
- After substituting $(z_L/H)^{-2/3} = H^{-2/3} z_L^{-2/3}$, the expression simplifies to Equation 6.

Variables: z_L is the smoke-layer interface height above floor; H is ceiling height above the fire source; A is the effective horizontal smoke reservoir area; k_v is the volumetric entrainment coefficient; and $\dot{Q}_c$ is convective heat release rate.

Natural venting mass-flow equation

For the actual open-sided condition, the calculation checks buoyancy-driven natural vent discharge against plume smoke production. The drawing-stated clear areas are used directly as A_v . No additional 0.6 factor is applied.

$$\dot{m} = (2\rho_o^2 g)^{1/2} \left(\frac{T_o \Delta T}{T} \right)^{1/2} A_v d^{1/2} \quad (51.44)$$

Equation 7. SFPE Eq 51.44 natural vent mass-flow equation¹⁰.

where

$\dot{m}$ = Mass flow rate through vent (kg/s)

A_v = Flow area of vent (m²)

ρ_o = Density of ambient air (kg/m³)

g is acceleration due to gravity

T_o is ambient absolute temperature; T is smoke-layer absolute temperature; Delta T is smoke-layer temperature rise

⁸ Milke, 'Smoke Control by Mechanical Exhaust or Natural Venting' in Hurley (ed), SFPE Handbook (5th edn, Springer 2016) 1833, Eq 51.22; F W Mowrer, 'Enclosure Smoke Filling' in Hurley (ed), SFPE Handbook (5th edn, Springer 2016) 1083, Eq 33.38.

⁹ Derived from Milke, SFPE Handbook (5th edn, Springer 2016) 1833, Eq 51.22; not separately numbered in the handbook.

¹⁰ Milke, SFPE Handbook (5th edn, Springer 2016) 1843-1844, Eq 51.42-Eq 51.45. Eq 51.44 has no stand-alone discharge coefficient.

$d = H - z_L$ is smoke-layer depth

Plume mass-production equations

Smoke production into the upper layer is checked using the SFPE/Heskestad axisymmetric plume expressions. Because vehicle fire geometry is not an ideal circular pool fire, this report takes the larger of the two Heskestad plume alternatives as a conservative project envelope.

For clear heights less than the limiting height, i.e., where flames extend into the smoke layer, the entrainment rate is estimated using Equation 51.26

$$\dot{m} = 0.032 \dot{Q}_c^{3/5} z \quad (51.26)$$

For clear heights greater than the limiting height, i.e., where the flaming region ends prior to reaching the smoke layer, the entrainment rate is estimated using Equation 51.27:

$$\dot{m} = 0.071 \dot{Q}_c^{1/3} z^{5/3} + 0.0018 \dot{Q}_c \quad (51.27)$$

Equation 51.27 is a simplified version of the original expression developed by Heskestad (see

Equation 8. SFPE/Heskestad plume mass-flow expressions¹¹.

$$\dot{m}_p(z) = \max(\dot{m}_{p,1}, \dot{m}_{p,2})$$

Calculation Rule 1. Conservative project envelope for plume production; not a separate handbook equation¹².

Opening area above the smoke layer and equilibrium condition

Only the portion of each opening above the selected smoke-layer interface is credited. It simply calculates the A_v variable used in the SFPE natural-vent equation. See equation 7, earlier.

$$A_v(z) = \sum_i w_i [\min(h_i, H) - z] +$$

Calculation Rule 2. Project-specific geometric opening area above the smoke interface; not a handbook equation¹³.

The notation $[+]$ means negative values are taken as zero. If the smoke interface is above an opening, that opening contributes no vent area.

¹¹ Milke, *SFPE Handbook* (5th edn, Springer 2016) 1834, Eq 51.26-Eq 51.27.

¹² Project-specific conservative selection rule using SFPE Eq 51.26-Eq 51.27; not a handbook-numbered equation.

¹³ Project-specific geometry rule for calculating A_v from drawing widths and heights; not a handbook-numbered equation.

$$\dot{m}_v(z) = \dot{m}_p(z)$$

Calculation Rule 3. Project mass-balance condition for a stable naturally vented smoke layer; not a separate handbook equation¹⁴.

In simple words: when the smoke leaving through the openings ($\dot{m}_v(z)$) equals the smoke supplied by the plume ($\dot{m}_p(z)$), the smoke layer stops descending. That height is the predicted equilibrium smoke-layer height.

7. Smoke accumulation and descent

Conservative no-vent check

The following table ignores the openings entirely. It is included to show the conservative upper bound on smoke-layer descent before crediting the very large permanent opening area.

Table 4. No-vent smoke-layer descent times

Geometry	Fire	Time to z=2.5 m (min)	Time to z=2.0 m (min)	Time to z=1.8 m (min)
H=7.5 m, A=700 m ²	2 MW	6.89	9.02	10.14
H=7.5 m, A=700 m ²	5 MW	5.08	6.64	7.47
H=7.5 m, A=700 m ²	8 MW	4.34	5.68	6.39
H=7.5 m, A=2275 m ²	2 MW	22.39	29.31	32.95
H=7.5 m, A=2275 m ²	5 MW	16.50	21.60	24.28
H=7.5 m, A=2275 m ²	8 MW	14.11	18.46	20.76

Even when the openings are ignored, the severe 8 MW case with the conservative 700 m² reservoir gives approximately 5.68 min to reach 2.0 m and 18.46 min with reservoir of 2275 m². The actual condition is more favorable because the space has large permanent openings.

Opening area above the smoke layer

Table 5. Credited opening area above selected smoke-layer heights

Ceiling-height case	Smoke interface z _L (m)	Opening area above layer A _v (z) (m ²)
H=7.5 m	5.5	53.67
H=7.5 m	5.0	72.37
H=7.5 m	4.0	134.07
H=7.5 m	3.0	197.21
H=7.5 m	2.5	231.06
H=7.5 m	2.0	264.91
H=7.5 m	1.8	278.45

The available vent area increases rapidly as the smoke layer deepens. At z_L = 2 m, even the low-height case has approximately 264.91 m² of vent area above the interface. This is very large compared with a single vehicle plume.

Example at z = 2.0 m and H = 7.5 m:

- $A_v = 15(7.0-2.0) + 7.9(6.7-2.0) + 6.7(6.7-2.0) + 3.9(7.0-2.0) + 3.9(7.5-2.0) + 6.0(3.24-2.0) + 24.3(5.0-2.0)$.
- $A_v = 264.91$ m² of clear vent area above the 2.0 m smoke interface.

¹⁴ Project-specific mass-balance condition; see *Milke, SFPE Handbook* (5th edn, Springer 2016) 1833-1834.

Natural vent capacity compared with plume production

Table 6. Natural vent capacity at tenability heights

H (m)	z _L (m)	Vent capacity, ΔT=5K (kg/s)	5 MW plume (kg/s)	Ratio	8 MW plume (kg/s)	Ratio
7.5	2.5	211.6	10.7	19.8	14.2	14.9
7.5	2.0	254.5	8.6	29.7	11.4	22.4
7.5	1.8	272.3	7.7	35.3	10.2	26.7

The vent capacity exceeds the 8 MW plume production by approximately 22.4 times at $z_L = 2.0$ m for $H = 7.5$ m. With such a big ratio of vent capacity : plume production, the smoke interface will not descend to an adult human standing level. On this simple analysis, it is not necessary to go further into predicting equilibrium smoke layer height.

8. Calculation considering 3.0 m vehicle-exclusion barrier and local heat exposure

The 3.0 m physical exclusion zone materially changes the level of safety or tenability in the proximity of the stair 04 termination because the vehicle fire is no longer located at its door. It does not, however, eliminate direct radiation from a fully developed vehicle fire.

Two distances are used. The first is $R = 3.0$ m, representing a conservative direct source-to-door screening distance. The second is $R = 3.9$ m, representing a side-on saloon car where the nearest vehicle envelope is 3.0 m from the door and the fire source is approximated near the vehicle centreline about 0.9 m further away.

Table 7. Point-source radiant heat flux to Stair 04 zone

Fire size	q" at R=3.0 m (kW/m ²)	q" at R=3.9 m (kW/m ²)
2 MW	6.19	3.66
5 MW	15.47	9.16
8 MW	24.76	14.65

Table 8. Approximate point-source distance needed for selected radiant heat screens

Fire size	Distance for 2.5 kW/m ² (m)
2 MW	4.72
5 MW	7.46
8 MW	9.44

The result shows that all radiant heat flux values exceed the strict 2.5 kW/m² tenability screen.

The result means a physical barrier cannot be treated merely as a parking-control line. It must physically keep vehicles away. The route should not require occupants to stand, queue or turn back within the heat radiation zone.

The SFPE heat exposure material treats 2.5 kW/m² as a conservative radiant heat tenability threshold. This is why the report retains conditions on barrier form and route management even though bulk smoke layer descent is acceptable¹⁵.

Sprinkler effect

The sprinkler system is beneficial and supports acceptance, but it is not treated as instant extinguishment. A passenger vehicle fire may be shielded by the vehicle body, underbody, interior compartments, glazing and fuel-package layout. Sprinkler operation is therefore credited as controlling fire growth and reducing sustained HRR, rather than as removing the design fire at the moment of activation.

¹⁵ Purser and McAllister (n 1) 2417; Beyler (n 9) 2656-2657.

The 2 MW case in the calculation represents a sprinkler-controlled condition. Sprinkler control therefore gives substantial margin above occupant height and protects the evacuees against radiant heat flux.

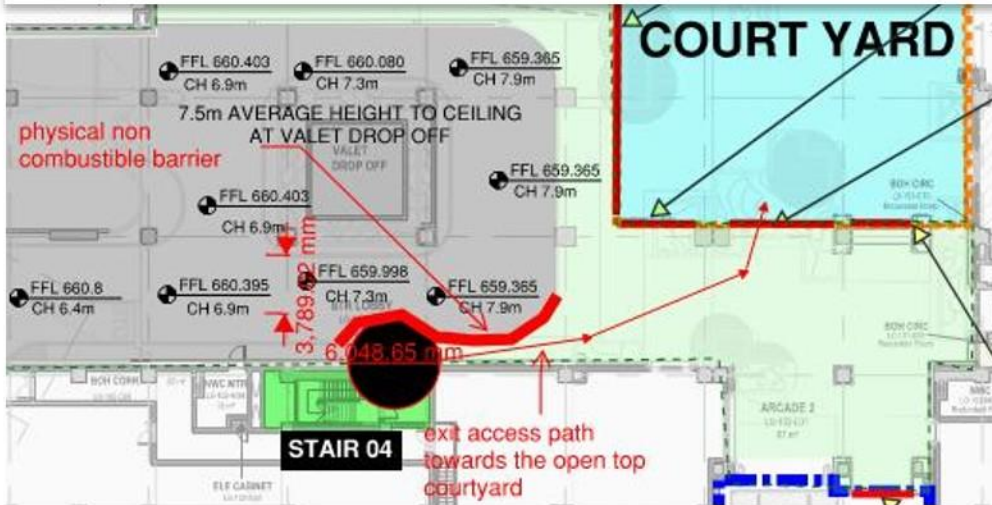
9. Engineering conclusion

The hand calculated engineering conclusion is, exit stair 04 termination at the proposed valet drop-off location is conditionally acceptable from a smoke accumulation and smoke layer descent standpoint, provided that a 3.0 m vehicle exclusion is permanent, physical, enforceable and maintained, and provided that occupants leaving stair 04 have a clear onward route to public way without passing through the vehicle fire plume or waiting within the direct radiation zone.

Based on the vehicle exclusion barrier, the detailed opening schedule, the sprinklered condition, and the actual valet-zone height, the hand calculation predicts that bulk smoke accumulation will remain high in the naturally vented space and will not descend to the ordinary standing-occupant tenability heights.

Mandatory acceptance conditions

- The 3.0 m exclusion zone shall be measured from the stair 04 discharge door / exit path to the nearest possible vehicle envelope, not merely to a wheel-stop line.
- The exclusion shall be achieved by robust non-combustible physical barriers: bollards, kerbs, walls, planters or an equivalent vehicle-restraint arrangement. Painted markings and signs alone are not sufficient.
- Since the stair 04 discharge route has direct line of sight to a permissible vehicle fire position, a physical barrier to be provided, which should be designed as, or supplemented by, a non-combustible radiant-heat screen.
- No valet desk, kiosk, electrical cabinet, refuse, luggage trolley, furnishing, combustible decorative combustible or storage item should be placed in the 3.0 m exclusion zone or along the stair 04 discharge path towards the courtyard.
- The clear opening area used in the calculation shall remain permanently unobstructed. Future permanent or temporary screens, advertisements, roller shutters, facade works or barriers reducing this area require re-assessment.
- The sprinkler system serving the valet drop-off zone shall be maintained and must not be deleted.
- The egress route from stair 04 to public way shall not require occupants to pass between the burning vehicle, queue beside the vehicle, or reverse direction past the vehicle fire source.



Layout showing valet drop-off zone, Stair 04, with the physical barrier as described earlier

10. Appendix A - Radiant heat explanation and transparent derivation

This appendix explains the local radiant heat issue in plain language. Smoke-layer descent and radiant heat are different hazards. The smoke calculation shows that the smoke layer will remain high. Radiant heat is more immediate because it travels by line-of-sight from the burning vehicle to a person leaving the stair. It is therefore checked separately.

A.1 Point-source radiant heat equation and simplification

The SFPE point-source radiation model gives incident heat flux from a radiating fire source. The SFPE Handbook gives the point-source form and the radiative heat-release relationship as separate equations.

The incident radiative heat flux is given by

$$\dot{q}'' = \frac{\dot{Q}_r \cos \theta}{4\pi R^2} \quad (66.12)$$

The radiative energy output is given by the radiative fraction, χ_r , multiplied by the total heat release rate:

$$\dot{Q}_r = \chi_r \dot{Q} = (0.21 - 0.0034D) \dot{Q} \quad (66.15)$$

Equation A1. SFPE point-source radiant heat equation and radiative HRR relationship¹⁶.

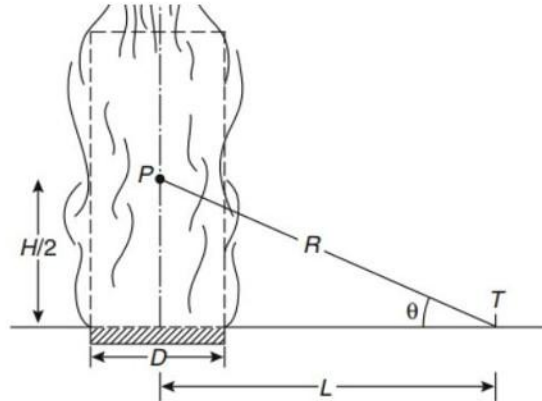


Fig. 66.15 Nomenclature for use with the point source model

For a conservative direct line-of-sight screening calculation, the target is assumed to face the source directly. That means $\cos(\theta) = 1$. Thus, the point-source equation gives the simplified project equation below.

$$\dot{q}'' = \frac{\chi_r \dot{Q}}{4\pi R^2} \quad (\cos \theta = 1)$$

Equation A2. Derived direct line-of-sight point-source heat flux; not separately numbered in the handbook¹⁷.

$$R_{\dot{q}''} = \left(\frac{\chi_r \dot{Q}}{4\pi \dot{q}''} \right)^{1/2}$$

Equation A3. Rearranged point-source distance for a selected radiant heat flux; derived from Equation A2¹⁸.

Derivation of Equation A3: multiply both sides of Equation A2 by R^2 , divide by q'' , then take the square root. This gives the distance needed to reduce incident radiant heat to a selected value.

A.2 Flame-height screening equation

The Heskestad flame-height relationship is included only as a screening check. It was developed for open hydrocarbon fires and should not be treated as a detailed saloon-car flame-shape model.

¹⁶ C L Beyler, 'Fire Hazard Calculations for Large, Open Hydrocarbon Fires' in Hurley (ed), SFPE Handbook (5th edn, Springer 2016) 2602-2604, Eq 66.12 and Eq 66.15.

¹⁷ Derived from Beyler, SFPE Handbook (5th edn, Springer 2016) 2602-2604, Eq 66.12 and Eq 66.15; not separately numbered.

¹⁸ Derived from Beyler, SFPE Handbook (5th edn, Springer 2016) 2602-2604, Eq 66.12 and Eq 66.15; not separately numbered.

meters is given by the Heskestad [42] correlation, Equation 66.13:

$$H = 0.235\dot{Q}^{2/5} - 1.02D \quad (66.13)$$

where $\dot{Q}$ is the heat release of the pool fire in kW and D is the diameter of the pool fire in meters.

Equation A4. Heskestad flame-height relationship used only as a screening check¹⁹.

A.3 Radiant heat tenability interpretation

NFPA 502 gives approximately 2.5 kW/m² as a radiant heat tenability screening value for skin exposure and gives an empirical equation for time to skin burning above that threshold, as shown below

[B.2.1a]

$$t_{rad} = \frac{416}{\gamma} (q)^{-1.56}$$

where:

t_{rad} = time to burning of skin due to radiant heat (seconds)

416 = empirical constant (kW/m²)^{1.56}·s

q = radiant heat flux (kW/m²)

γ = safety factor, 1.6

Equation A5. NFPA 502 radiant heat skin-burning time relationship²⁰.

$$FED_{rad} = \frac{t_{exposure}}{t_{I,rad}}$$

This is a simple ratio of radiant heat exposure time to a person and time a skin will burn due to the radiant heat.

So:

$$FED_{rad} < 1.0$$

means the person's exposure time is shorter than the calculated burn time.

$$FED_{rad} = 1.0$$

means the person has reached the predicted skin-burning exposure duration.

$$FED_{rad} > 1.0$$

¹⁹ Beyler, *SFPE Handbook* (5th edn, Springer 2016) 2602-2603, Eq 66.13.

²⁰ NFPA 502: *Standard for Road Tunnels, Bridges, and Other Limited Access Highways* (2017 edn, NFPA 2017) annex B, B.2.1, Eq B.2.1a, 502-41.

means the exposure is not acceptable for that heat flux and duration.

Equation A6. Simple fractional exposure interpretation used qualitatively in this report; not a separate NFPA equation²¹.

A.4 Radiant heat calculation at the 3 m vehicle-exclusion barrier

The following table applies Equation A2 using radiative fraction $FED_{rad} = 0.35$. The value $R = 3.0$ m is the strict physical exclusion distance. The value $R = 3.9$ m represents a simple centreline sensitivity where the vehicle envelope is kept 3.0 m away but the main burning source is nearer the centre of the vehicle.

Table A1. Point-source radiant heat flux at selected separation distances.

Separation R (m)	2 MW q'' (kW/m ²)	5 MW q'' (kW/m ²)	8 MW q'' (kW/m ²)
3.0	6.19	15.47	24.76
3.9	3.66	9.16	14.65
5.0	2.23	5.57	8.91
7.5	0.99	2.48	3.96

Table A2. Distance required to reduce point-source radiant heat to 2.5 kW/m².

Fire size	Distance for 2.5 kW/m ² (m)
2 MW	4.72
5 MW	7.46
8 MW	9.44

Table A3. Approximate skin-burning time from NFPA 502 Eq B.2.1a.

Separation R (m)	2 MW skin-burn time (s)	5 MW skin-burn time (s)	8 MW skin-burn time (s)
3.0	20.1	5.8	3.1
3.9	41.1	11.8	6.2
5.0	80.7	23.2	12.3
7.5	243.2	69.9	36.9

Figure A1. Point-source radiant heat flux versus separation distance.

A simple explanation is, taking 3.66 kW/m² from Table A1, row 3, column 2. Equation B.2.1a will give $t_{rad} = 34.4$ s. If a person is exposed to 3.66 kW/m² for 5 seconds, FED_{rad} will be 0.15. This means a person is only exposed to 15% of the predicted time to skin burn.

Now if the person is exposed for 60 seconds, FED_{rad} will be 1.74. This means the same person has long been suffering from a burnt skin.

A.5 Radiant heat interpretation for stair 04

The 3 m vehicle exclusion does not make radiant heat negligible. At exactly 3.0 m, even a 2 MW sprinkler-influenced fire gives a calculated point-source flux above 2.5 kW/m². That does not automatically reject the exit termination because the exposure is transient, the area is sprinkler-protected, occupants are moving, and the smoke layer remains high. However, it does mean occupants must not queue or wait at the stair 04 discharge.

The correct design response is to treat the 3 m barrier as more than a painted line. It should be a robust physical vehicle barrier and, where direct line-of-sight to the nearest vehicle fire is possible, it should also provide non-combustible shielding or route occupants immediately away from the vehicle-fire side. With those controls, local radiant heat is manageable and does not defeat the overall acceptance conclusion.

²¹ Project-level FED interpretation of NFPA 502 annex B, B.2.1; not a separate numbered NFPA equation.

11. Appendix B - Calculation summary for reviewers

Table B1. Key calculation outputs.

Item	Value	Comment
Total clear opening area	400.70 m ²	Drawing-stated clear areas; no 0.6 factor
Adopted smoke-analysis ceiling height	7.5 m	Known average height used as the sole basis for the smoke-descent analysis
Main conservative reservoir area	700 m ²	Used for simple no-vent screen
Sprinkler-influenced fire	2 MW	Controlled / early controlled case
Developed car fire	5 MW	NIST-supported developed single car order of magnitude
Severe sensitivity	8 MW	NIST-supported severe single car order of magnitude
Severe 8 MW equilibrium, H=7.5 m, $\Delta T=10$ K	6.09 m	Above 2.5 m, 2.0 m and 1.8 m
Final decision	Acceptable with controls	Smoke descent not governing; radiant heat controlled by barrier/route/screening

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