Protocols for Mitigating Cladding Risk Support Package

D.02 – External Fire Threats to Cladding

Version 2
Date: 13 March 2024

Aboriginal acknowledgement

Cladding Safety Victoria respectfully acknowledges the Traditional Owners and custodians of the land and water upon which we rely. We pay our respects to their Elders past, present and emerging. We recognise and value the ongoing contribution of Aboriginal people and communities to Victorian life. We embrace the spirit of reconciliation, working towards equality of outcomes and an equal voice.

Application of Minister's Guideline 15

These documents contain information, advice and support issued by CSV pursuant to Minister's Guideline 15 - Remediation Work Proposals for Mitigating Cladding Risk for Buildings Containing Combustible External Cladding. Municipal building surveyors and private building surveyors must have regard to the information, advice and support contained in these documents when fulfilling their functions under the Act and the Regulations in connection with Combustible External Cladding on buildings:

a) which are classified as Class 2 or Class 3 by the National Construction Code or contain any component which is classified as Class 2 or Class 3;

b) for which the work for the construction of the building was completed or an occupancy permit or certificate of final inspection was issued before 1 February 2021; and

c) which have Combustible External Cladding.

For the purposes of MG-15, Combustible External Cladding means:

a) aluminium composite panels (ACP) with a polymer core which is installed as external cladding, lining or attachments as part of an external wall system; and

b) expanded polystyrene (EPS) products used in an external insulation and finish (rendered) wall system.

Disclaimer

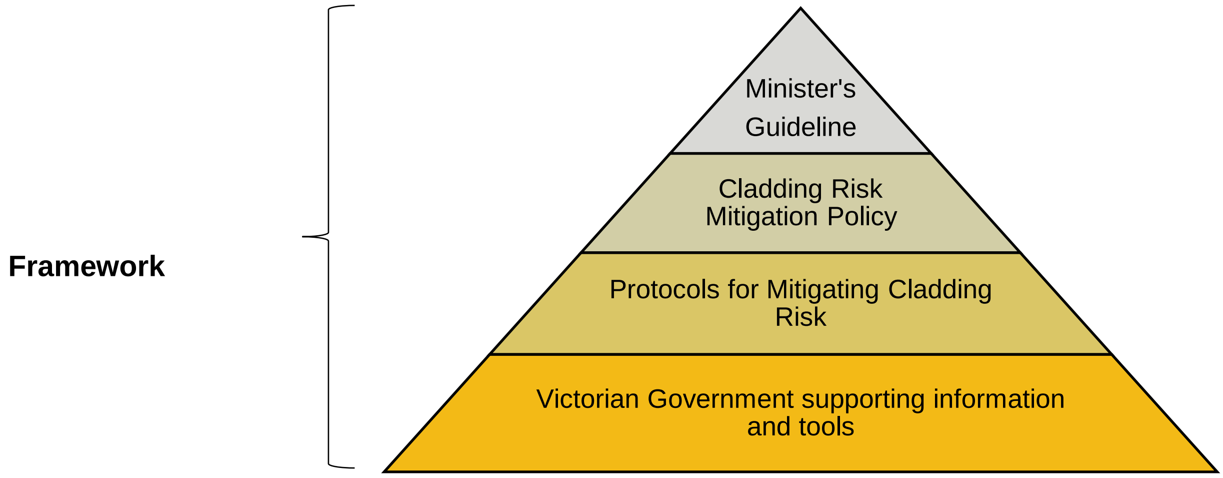
These documents have been prepared by experts across fire engineering, fire safety, building surveying and architectural fields. These documents demonstrate CSV's methodology for developing Remediation Work Proposals which are intended to address risks associated with Combustible External Cladding on Class 2 and Class 3 buildings in Victoria. These technical documents are complex and should only be applied by persons who understand how the entire series might apply to any particular building. Apartment owners may wish to contact CSV or their Municipal Building Surveyor to discuss how these principles have been or will be applied to their building.

CSV reserves the right to modify the content of these documents as may be reasonably necessary. Please ensure that you are using the most up to date version of these documents.

Document notes

The Protocols for Mitigating Cladding Risk (**PMCR**) is an approach developed by Cladding Safety Victoria (**CSV**) on behalf of the Victorian Government to consistently and systematically address the risk posed by the presence of combustible cladding on Class 2 and Class 3 buildings (being multi-storey residential structures). For many buildings, combustible cladding on the facade:

- does not present a high enough level of risk to warrant substantial or complete removal of the cladding; but
- presents enough risk to warrant a tailored package of risk mitigation interventions to be introduced that provide a proportionate response to the risk.



A set of documents has been assembled to describe the purpose, establishment, method, findings and application of the PMCR. The full set of PMCR documents and their relationship to each other is illustrated in a diagram in *Appendix A – PMCR document set and flow*.

There are **seven** related streams of technical document in the PMCR document set:

A. Authorisation	Codifies the Victorian Government decisions that enable PMCR activation.
B. CRPM Methodology	Specifies the Cladding Risk Prioritisation Model (CRPM) method used for assessing cladding risk and assigning buildings to three risk levels.
C. PMCR Foundation	Defines the PMCR method, objectives and the key design tasks.
D. Support Packages	Captures the relevant risk knowledge and science-based findings necessary to systemise and calibrate PMCR application.
E. CSV Cladding Risk Policy	Establishes key CSV policy positions in relation to cladding risk.
F. PMCR Interventions	Identifies and describes the interventions that the PMCR method can employ to mitigate risk associated with combustible cladding.
G. Implementation	Specifies the standards and procedures that guide PMCR application.

This current document is one of a suite of supporting research papers that provides the findings and analysis that act to inform the PMCR design.

Table of Contents

Abbreviations

Term	Meaning
ACP-PE	Aluminium Composite Panel with a polyethylene core
CRMF	Cladding Risk Mitigation Framework
CSV	Cladding Safety Victoria
EPS	Expanded Polystyrene
EV	Electric Vehicle
FDS	Fire Dynamics Simulator
Framework	Cladding Risk Mitigation Framework
ICE	Internal Combustion Engine
IF-SCAN	Initial Fire Spread in Cladding Assessment Number
MBS	Municipal Building Surveyor
MG-15	Minister's Guideline 15
NCC	National Construction Code
PMCR	Protocols for Mitigating Cladding Risk
RWP	Remediation Work Proposal
SOU	Sole Occupancy Unit as defined in the National Construction Code

1 Summary

This report has been developed to analyse ground-level external fire threats and the radiative impact these threats have on external walls with combustible cladding installed. The objective of the report is to analyse the radiative impact of ground-level fire sources on a test wall and the critical ignition heat flux limits of the polymers, polystyrene and polyethylene, being the flammable polymers of Expanded Polystyrene and Aluminium Composite Panels.

The research strengthens Cladding Safety Victoria's (CSV) risk reduction decision making processes through targeted cladding removal by resolving the following key **research questions**:

1. When are the polymers in ACP PE and EPS subject to plausible critical ignition radiation levels, when they are exposed to an external fire source hazard?
2. What is the extent of cladding removal required in instances that a ground-based ignition threat is present?

Numerical analysis using Fire Dynamics Simulator (FDS) were created to investigate the radiative impacts of both vehicle and rubbish bin fires on a test wall. For both scenarios, a heat flux map was generated to highlight regions on the wall that could potentially reach critical ignition heat flux levels for the polymers found in two in-scope combustible cladding systems: expanded polystyrene wall systems (EPS) and aluminium composite panels (ACPs).

The simulation of radiative exposure heat flux levels at the test wall indicated radiation levels that could theoretically lead to the ignition of unprotected uncovered and exposed polyethylene and polystyrene. The radiative heat flux experienced at the test wall is directly influenced by the distance of the fire source from the test wall. As anticipated, the proximity of a fire hazard to the test wall correlates with an increased likelihood of cladding ignition, where vehicle fires present a worst-case scenario with respect to thermal radiation emitted.

The results suggest that, when feasible, the consideration of cladding removal is advisable, with adherence to the following general statements:

Carparking proximal to combustible cladding

ACP *PE*

The analysis supports that where designated carparks are located less than **3m horizontally away** from installed ACP, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **2.25m away** horizontally from installed ACP, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

EPS

The analysis supports that where designated carparks are located less than **2m horizontally away** from installed EPS, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **1.25m away** horizontally from installed EPS, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

Carpark removal

An approach that involves retaining the combustible cladding but removing or blocking parking areas can be implemented to achieve the intent of safe distances for EPS and ACP PE highlighted above.

Motorcycles

Under rule 197b of the road safety rules 2017, motorcycles can park on shared paths providing that the vehicle is positioned so that it does not ‘obstruct, hinder or prevent the free passage of any pedestrian’. Additionally, the Victorian Rider Handbook 2023 explicitly states ‘Do not park too close to the building line, as this can create an obstruction to vision impaired pedestrians. This suggests that a motorcycle parked adjacent walls with combustible cladding installed and on fire would be considered a highly unlikely event.

Wastebins proximal to combustible cladding

The following management in use procedures should apply for designated wastebin areas:

ACP *PE*

The analysis supports that where designated bin areas are located less than **3m horizontally away** from installed ACP, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated bin areas is less than **1.75m away** horizontally from installed ACP, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

EPS

The analysis supports that where designated bin areas are located less than **1.5m horizontally away** from installed EPS, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated bin areas is less than **1m away** horizontally from installed EPS, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

2 Introduction

When a building has combustible cladding on the facade, an **intervention** may be necessary to enhance life safety and reduce cladding fire risk to an acceptable level.

The level of risk created by the presence of combustible cladding varies substantially from building to building. Accordingly, a decision to **intervene** and the extent of **intervention** required must also vary.

The Victorian Government has authorised the use of **15 interventions** to mitigate cladding risk. The authority for their use is contained in *Minister's Guideline 15* (**MG-15**) and supported by the Cladding Risk Mitigation Framework (**Framework**).

The Guideline and Framework are intended to:

- Support Municipal Building Surveyors (**MBS**) in rating the cladding risk of a building; and
- Inform owners about how their building is assessed with regard to cladding risk and the structured way in which Remediation Work Proposals are developed to bring their building to an acceptable level of cladding risk.

Cladding Safety Victoria (**CSV**) is assisting MBSs and owners by providing information about the cladding risk associated with each building and the steps necessary to remedy that risk. This information is provided in the form of a Remediation Work Proposal (**RWP**), that applies the cladding risk methodologies developed by CSV over three years.

A threat barrier analysis can be used to represent how risk-mitigating actions can function to respond to a problem. The CSV method employs this analysis technique to identify the central problem (the 'top event'), in this case a cladding fire, and depict how risk associated with the problem can be mitigated through the implementations of barriers (interventions) designed to control the key hazards identified.

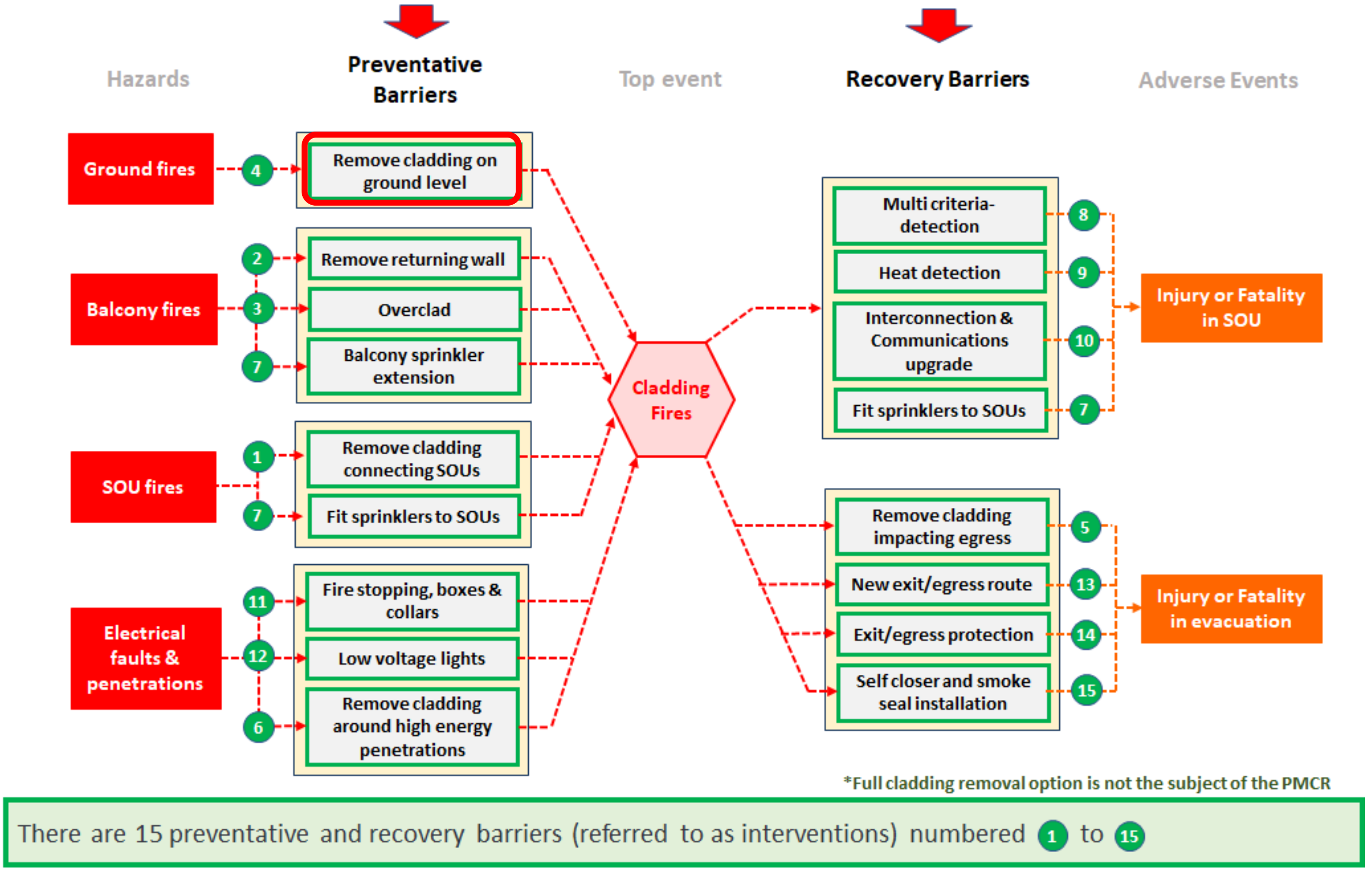


Figure 1: Threat barrier analysis

The 15 interventions in the threat barrier analysis act in different ways to mitigate cladding fire risk.

Each intervention may:

- Respond to one or more of the four identified hazards;
- Function to prevent an ignition source from spreading fire to cladding (i.e. interventions that reduce the likelihood of a fire igniting cladding); and/or
- Function to reduce the adverse impacts for building occupants once a fire has reached cladding (i.e. interventions that reduce the consequences of a cladding fire).

Any risk mitigation solution designed under the Framework must target credible hazards on a building and balance both cladding ignition likelihood and consequence considerations.

2.1 Purpose of this report

Where high-energy fuel loads are present in close proximity to combustible cladding, there is an escalation in the risk of combustible cladding ignition that can subsequently spread to Sole Occupancy Units (SOUs) and endanger building occupants.

Two significant examples of high-energy fuel loads are vehicles (car parking) and waste bins where they are stored in relation to apartment waste collection areas.

The purpose of this paper is to provide an enhanced research-based understanding of these external threats in order to inform PMCR judgements about:

Research Question 1	When are the polymers in ACP PE and EPS subject to plausible ignition radiation levels, when exposed to an external fire source hazard?
Research Question 2	What is the extent of cladding removal required in instances that a ground-based ignition threat is present?

The research methodology in this support package combines literature reviews, experimental testing, expert judgements, and comprehensive Fire Dynamics Simulator (FDS) analysis. A full list of references is provided at the end of the document.

3 Literature review

Documented throughout literature are several modes in which a facade can be ignited, with traditional means being:

1. Flames propagate throughout an internal compartment to the point of flashover, causing the fire to break out of the room and ignite the external facade; or
2. Fire begins in an external private area such as a balcony, terrace, or a courtyard; or
3. External ignition is caused directly via a flaming object such as a vehicle or a waste bin being placed in close proximity to the façade [1]

Of these mechanisms of facade fires, several studies have investigated internal fire sources and the phenomenon of flashover [2-7]. Whereas a search of the published literature indicated to the research team that no centralised register of such events exists. With regard to the plausible external ignition threat, emphasis will be made on vehicle and waste bin fires owing to their high fuel load, urban prevalence and recorded frequency of being a source of ignition.

3.1 Vehicle fires

Vehicle fires, incorporating passenger car fires, can result for example from engines overheating, electrical malfunctions, or fuel leaks [8]. According to the "Fire in the United States 2008-2017" report [9], unintentional actions were identified as the primary cause of vehicle fires, accounting for 38% of incidents. The second leading cause, at 20%, was equipment failure, while in 24% of cases, investigations were unable to determine the specific cause of the vehicle fires.

The uptake of electric vehicles (EV) globally has increased significantly in recent times. Data released from EV Firesafe, an Australian Department of Defence backed electric vehicle focussed research group, highlights electrical vehicle battery fire occurrences over a 10-year period. The research shows that for nearly 400 documented and verified electric vehicle battery fires recorded worldwide, only four of the EV battery fires occurred in Australia. A direct comparison provided by the research company over the period suggests that the chances of an Internal Combustion Engine (ICE) car catching fire are 100 times greater than the chances of an electric vehicle catching fire based upon collected data for the period [10].

It is acknowledged that the fire dynamic behavior associated with electric vehicles and traditional internal combustion engines differ, whilst accepting that heat release rates may be similar. To illustrate, Macneil et al. [11] conducted research in 2015 to explore the energy released from various vehicles. The study involved an experiment in which vehicles were suspended above a 2MW fire. The heat release rates (HRRs) generated by vehicle fires were measured using oxygen consumption cone calorimetry. The results indicated that, regardless of vehicle type, an average HRR of 5-6MW with peaks reaching 8-9MW was recorded. The research concluded that the HRRs for the different vehicle types were similar, and that their HRR curves, regardless of engine type were comparable. These results align with a similar study conducted by Lecocq et al. in 2012 [12].

A 5MW passenger car design fire was selected for this report’s exposure analysis. The HRR value was considered conservative for a burning vehicle given that the 5MW HRR is sustained throughout the simulation period. Buoyant plume type flaming (in lieu of lower height jet flaming expected from battery thermal runaway) was selected for the simulation as it would expose a greater area of external wall cladding to flame radiation (at height). For simulation purposes, it is considered that the resultant flame heights for both vehicles are similar. It is noted that the HRR nominated for vehicle fires is congruous with international research undertaken by Cheong et al. [13] with reference to the recommendations of guidelines such as NFPA 502 [14], BD78/99 [15] and PIARC [16]. It is however acknowledged that EV ownership is increasing, and that research into the accuracy of current methods for measuring the total HRR from EV fires is ongoing.

3.2 Waste bin fires

Waste bin fires typically start from improperly discarded flammable materials or cigarettes in public areas like parks, residential neighbourhoods, and shopping centres.

In the event of waste bins igniting, there is the potential for flames to extend to adjacent waste bins located in designated waste bin areas, to nearby structures, and to other flammable materials.

The fire scenario may further escalate, especially if the source of the flaming is in proximity to another potential fire hazard, such as combustible cladding.

According to BS 5906:2005 [17], the heat release rate of a wheeled container with a volume of 1.1 m^3 is reported to be 930 kW (approximately 1MW). This study assumed an individual bin ignites and spreads to another, so that the fire scenario is two bins on fire in a single location as might be expected in a designated waste bin area. Our simulated waste bin fire scenario used a combined heat release rate of 2MW.

4 Experimental analysis – critical exposure limits

The mechanisms of external facade fire, and the fire growth behaviours of typical vehicle fires only frames half of the problem when discussed within the bounds of the PMCR and combustible cladding materials. The critical exposure limits of the polymers contained in each of the two eligible cladding materials, EPS and ACP PE, must be quantified to enable pragmatic and proportional remediation strategies. Testing was therefore undertaken at the RMIT University's materials testing laboratory to investigate the threshold of cladding ignition of the combustible polystyrene and polyethylene.

4.1 Methodology

The threshold of cladding ignition was generated using the Cone Calorimeter in accordance with ISO 5660-1 [18]. Rendered EPS and ACP PE were deconstructed from existing buildings in Victoria, Australia.

In order to investigate the ignition parameters of the polymers rather than the entire external cladding system, the testing materials were prepared as per the following:

- **EPS** - the render was removed, and the exposed EPS was used for testing.
- **ACP PE** - polymer cores of the ACP products were separated from the aluminium facets so that the core could be tested independently.

The 200mm × 200mm samples were tested in a vertical orientation to align with its configuration in facades (Figure 2). The threshold of cladding ignition was determined by the lowest heat flux that generated auto-ignition of samples; therefore, no pilot igniter was used.

Different heat fluxes were applied with a reducing increment of 10 kW/m^2 from 50 kW/m^2 until no ignition was observed after 30 minutes, after which the heat flux increments were reduced at 5kW/m^2 increments. At least five samples were exposed to each heat flux.

(a) *(b)*

Figure 2: The experiment setup; (a) EPS (b) PE

4.2 Experimental results

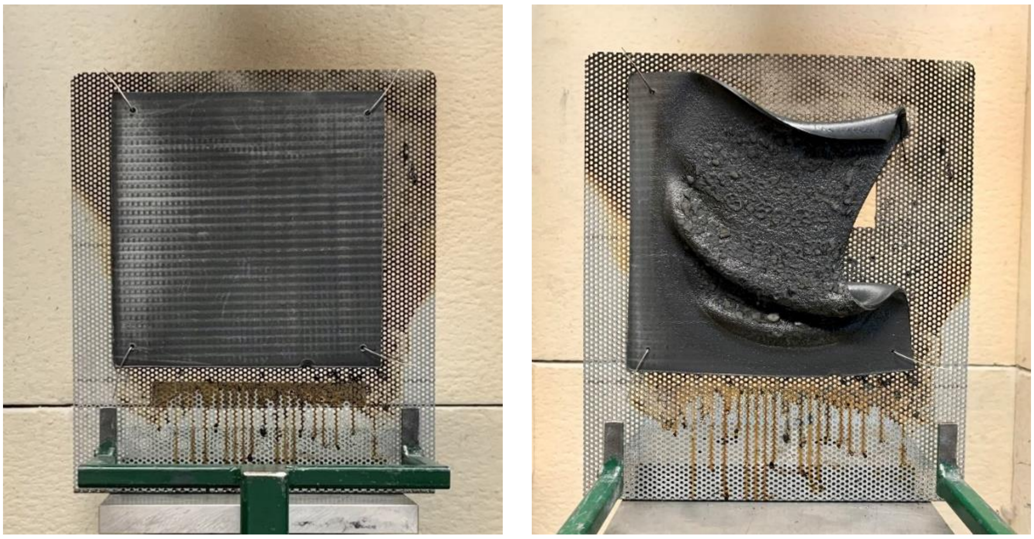
Table 1 presents the ignition time of EPS and PE under different heat fluxes. At least five samples were prepared to be expose to each specific heat flux level. The ignition time under each heat flux level that can ignite EPS and PE was averaged and summarised in Table 1. While the lowest heat flux to auto-ignite EPS is 35 kW/m^2 after 13.92 s ± 2.91 s, PE polymer cores were ignited at 15 kW/m^2 after 96.15 s ± 12.66 s. Figure 3 and Figure 4 show the state before and after the experiment of EPS and PE, respectively. The tests were terminated upon visual identification of any flaming.

Table 1: The result of the critical heat flux test for EPS and PE

Material	Heat flux (kW/m^2)	Percentage of ignited samples	Ignition time(s)
EPS	50	100%	12.84 ± 4.07
EPS	40	100%	12.98 ± 2.71
EPS	35	100%	13.92 ± 2.91
ACP PE	50	100%	19.91 ± 2.57
ACP PE	40	100%	23.46 ± 4.73
ACP PE	30	100%	31.38 ± 4.50
ACP PE	20	100%	66.36 ± 9.58
ACP PE	15	100%	96.15 ± 12.66

(a) *(b)*

Figure 3: Unrendered EPS; (a) before the test (b) after the test



(a) *(b)*

Figure 4: PE cores of aluminium composites; (a) before the test (b) after the test

5 Numerical analysis

5.1 Numerical setup

Computational fluid dynamic models were created using Fire Dynamics Simulator (FDS) software Version 6.7.9, with geometries constructed in Pyrosim Version 2022.2.0803. The aim was to analyse the impact of a burning vehicle or waste bins in proximity to combustible cladding on a building.

5.1.1 Fire scenarios

The following fire scenarios were developed to simulate the vehicle and wastebin fire scenarios:

5MW car fire	**The model consists of a simulated 5MW vehicle fire located at distances ranging from 0.5m to 3m, with an increment of 0.5m from a test wall, being the wall that is assumed to have combustible cladding.** To ensure a comprehensive evaluation incorporating directional wind analysis, the study deliberately excludes the explicit use of empirical vehicle fire HRR curves associated with vehicle fires (spikes) from the radiation analysis. Vehicle heat release curves generally indicate brief peaks with longer sustained periods of steady heat release both before and after the peak HRR is achieved. The research instead opted for a conservative and constant heat release rate for the purposes of generating wind-affected design fire conditions and radiative exposure analysis. The chosen peak heat release ramp for a single vehicle fire was capped at 5MW, with the peak achieved instantaneously and maintained for a period of 30 minutes. While it is acknowledged that the characteristics of electric vehicle fires are unique and may require different emergency responses, the flaming behaviour of a burning vehicle for the purposes of the simulations is considered a buoyant fire plume. This is deemed to be sufficiently conservative, given the comparable HRRs and total energy released for all types of vehicles. Adding to this, the main risk associated with electric vehicles is the batteries which are located at the base of the car, close to the ground.
2MW waste bin fire	**It was acknowledged that the intensity of a waste bin fire is less that that of a car fire, and as such, the number of burner positions away from the wall (increments) were reduced. The simulation of 2MW bin fire was carried out at distances ranging from 0m to 2m, with an increment of 0.5m from the test wall.**

Figure 5 illustrates the model domain, with the test wall and the proximal parking vehicle serving as the fire source.

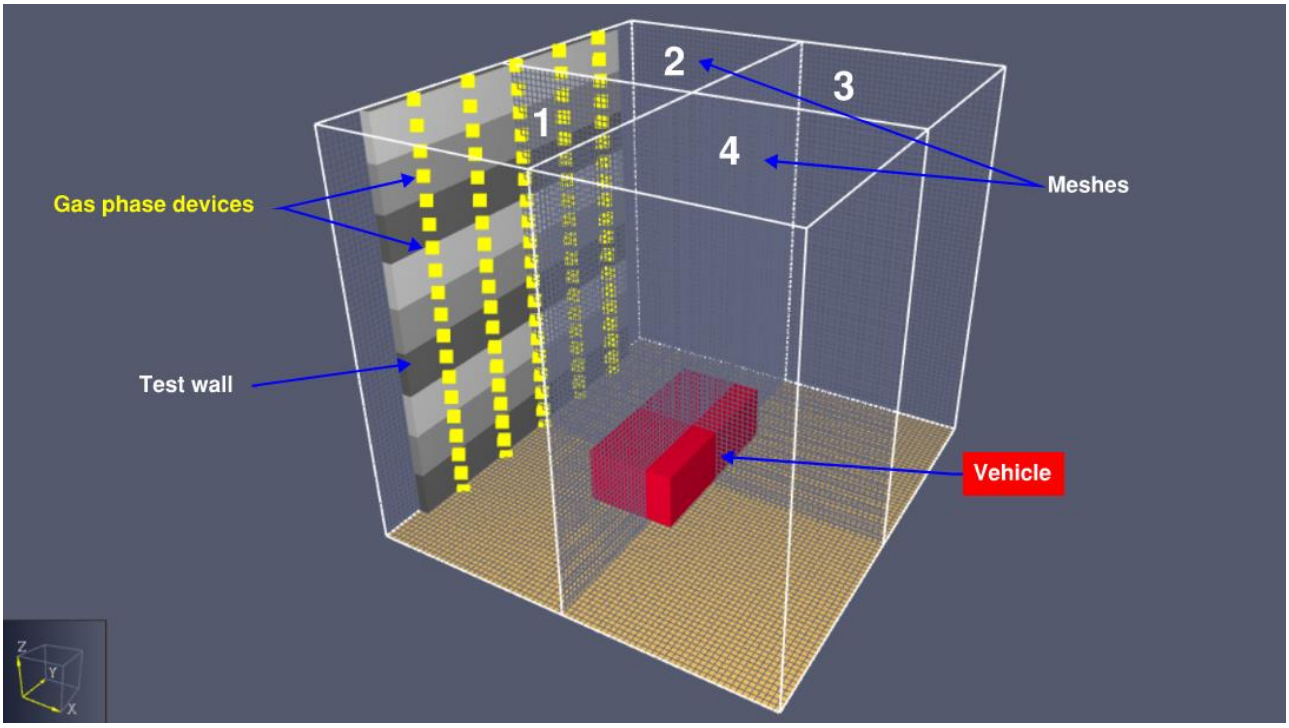


Figure 5: Modelled domain

5.1.2 Computational meshes

Domain

To optimise computing power and efficiency, the domain that was used for both the vehicle and bin fire scenarios is divided into four meshes. This division allows sufficient model resolution in addition to a reduction in the simulation time required for multiple iterations of the model. The sensitivity analysis was implemented to support parametric decision making with respect to mesh cell dimensions, burner size and fire-surface configuration.

The computational domain consists of 288,000 cells, with mesh cell dimensions of 0.125m x 0.125m x 0.125m (x, y, z). The recommendation grid size was estimated using the following equation [19]:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{2/5} \tag{1}$$

where D^* is the characteristic fire diameter, $\dot{Q}$ is the total heat release rate of the fire, ρ_∞ is the air density, c_p is the specific heat of air, T_∞ is the ambient temperature, and g is gravity. A grid with D^*/δ_X between 4 and 16 is desirable, where δ_X is the nominal size of the mesh cell. Using Eq. (1), an acceptable grid size in the current study is 0.125m for fire loads of 2MW and 5MW. The resulting D^*/δ_X value is approximately 15 for car fire simulation and 10 for bin fire simulation, all of which falls within the acceptable range.

A test wall with dimensions of 6m x 9m (width x height) is modelled with an “ADIABATIC” surface. At this stage, the focus is on the cladding area affected by the heat flux level required for auto-ignition of the material, so no heat flow is permitted across the wall boundaries. The key objective of the simulation is to extract a critical heat flux zone as it is to be experienced by the test wall proximal to a free-burning car fire or waste bin fire scenario.

5.2 Fire prescription

5.2.1 Vehicle fire scenario

It was considered that the number of burning surfaces attributed to the fire obstruction and the orientation of the burning surfaces would significantly influence the level of radiative heat flux impinging on the test wall in both the test cases.

To ensure that the selection of burning surfaces attributed to the obstruction was both realistic and conservative, two configurations were explored where the heat release rate attributed to the car fire was to be:

1. Attributed to the top and forward-facing surfaces (over a greater area with two impacting orientations), or
2. Attributed to the top surface only, with a smaller area (greater HRR per unit area, however no test wall-facing burning surface).

The flame configurations are represented in Figure 6.

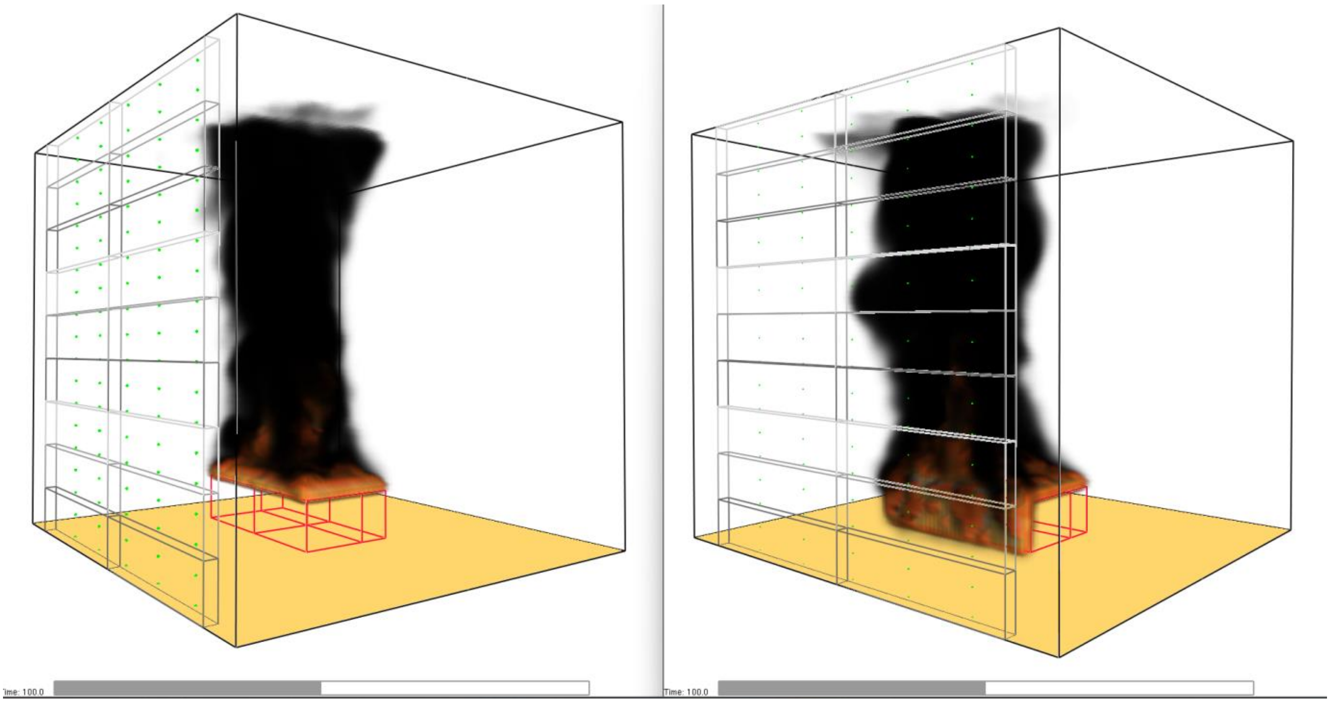


Figure 6: Smokeview visualisation of burning surfaces attributed to the (left) top only and to the (right) top and front facing surfaces of the burner (car)

The resulting radiative heat flux maps from two configurations are presented in Figure 7 and Figure 8 below.

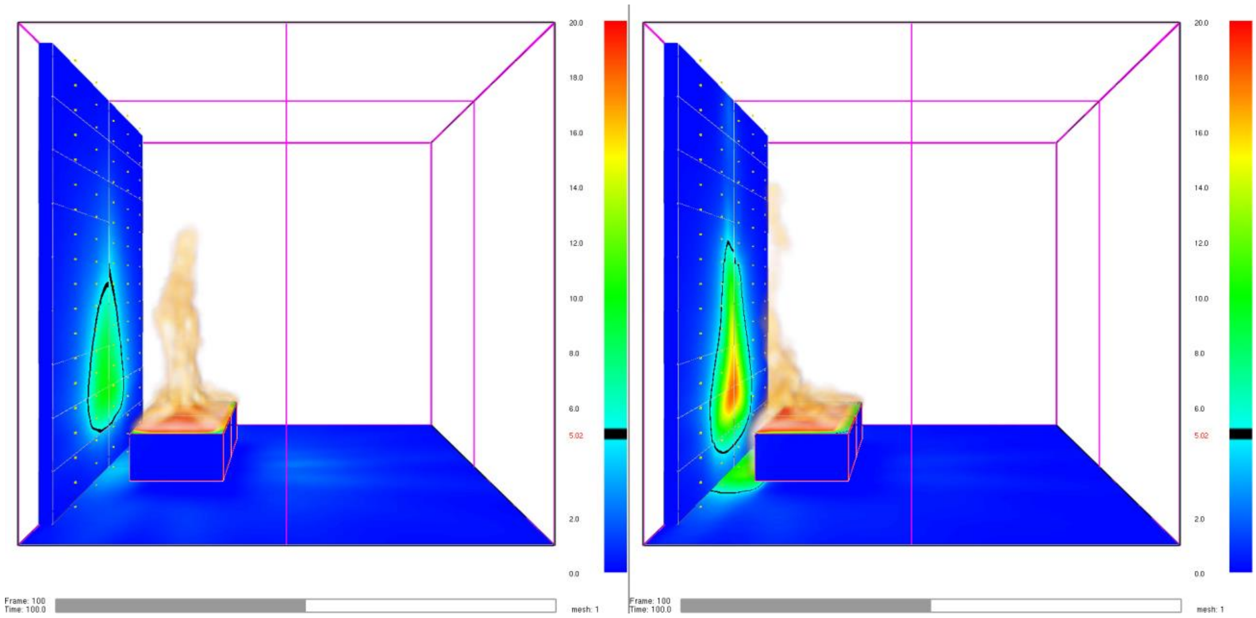


Figure 7: Parametric analysis (side view) of choice of burning surfaces attributed ‘Fire’ in the simulation. All other surfaces of the burner were assigned inert, with top surface only (left) and top and front burning surfaces combined (right)

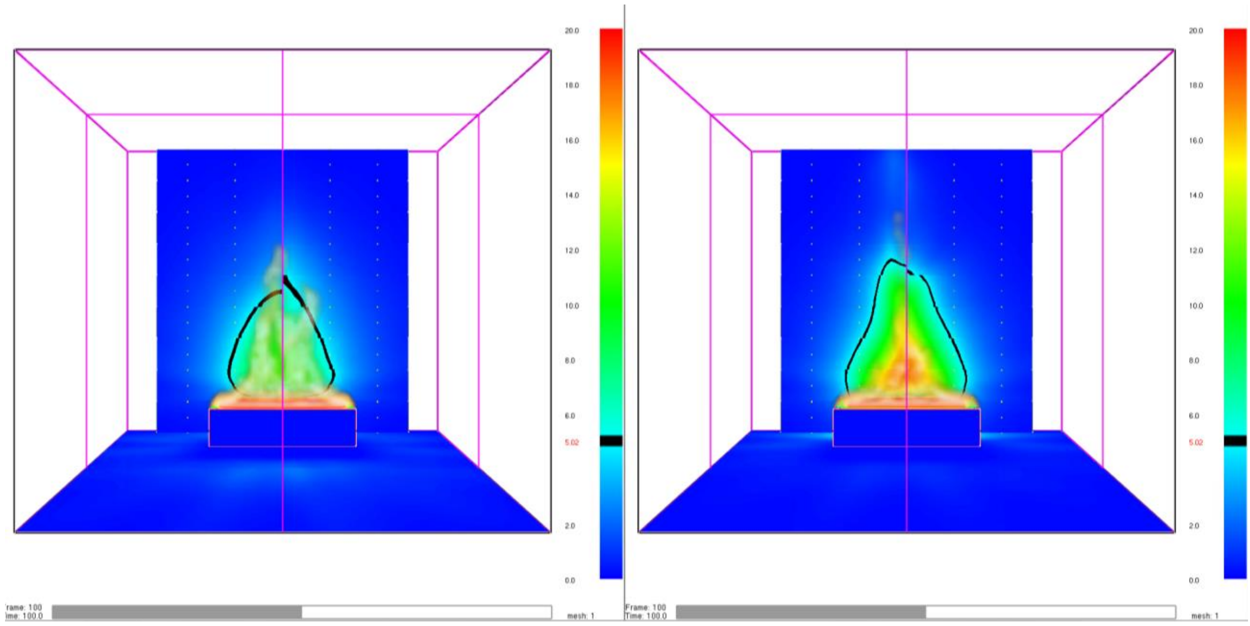


Figure 8: Parametric analysis (face view) of choice of burning surfaces attributed ‘Fire’ in the simulation. All other surfaces of the burner were assigned inert

As shown, the scenario pictured on the right, with a combination of vertically and horizontally oriented burners radiating at the test wall, produced the considered worst case scenario. The radiative impact from the multiple burning surfaces represented the worst-case configuration and the most conservative for the simulation’s approximation of a simulated car fire, thus implemented for the overall assessment of the car fires generated heat flux incident upon a test wall.

Vehicle geometry

A selection of simulated vehicle geometries were tested to determine the conservative area for which the design fire was to be attributed (Heat Release Rate per unit area). Sensitivity analysis was conducted with respect to the burner surfaces designated as 'Fire', which revealed that distributing the fire load over only the front and top surfaces was the most conservative (i.e., worst-case) configuration for the intended parametric analysis.

Table 2: Vehicle geometry sensitivity measurements

Vehicle type	Burner configuration (surfaces)	W	L	H
CommodoreT	5MW – Top surface	2.00	5.00	1.25
CommodoreTF	5MW - Top and Front surfaces	2.00	5.00	1.25
StandardT	5MW – Top surface	2.00	4.00	1.25
StandardTF	5MW - Top and Front surfaces	2.00	4.00	1.25
SubaruT	5MW – Top surface	1.83	4.63	1.25
SubaruTF	5MW - Top and Front surfaces	1.83	4.63	1.25

Comparisons were made for various vehicle dimensions to obtain a realistic obstruction size, supporting the design fire burner (Table 2).

Three different vehicles were considered for the sensitivity analysis:

- Commodore sedan (Commodore);
- Standard sedan averaged (Standard); and
- Subaru sedan (Subaru).

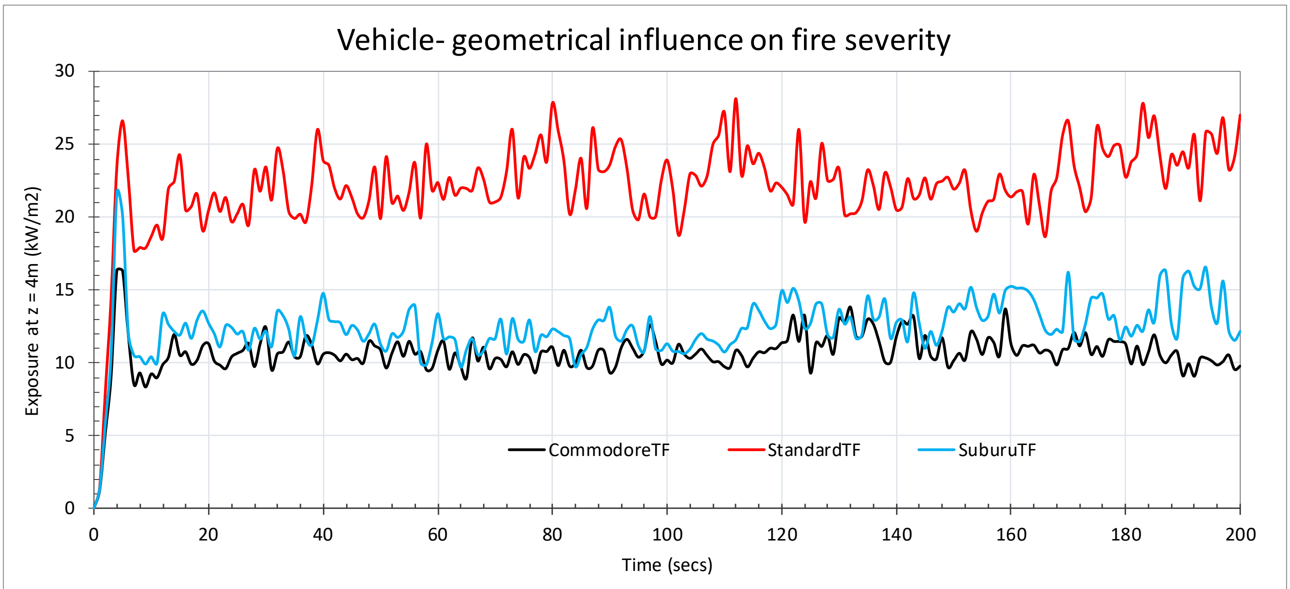


Figure 9: Assessing the exposure of varying simulated car fire geometries on test wall at z= 4m

Figure 9 presents the radiation incident at a height of 4m on the test wall when attributing the HRRPUA to the car 'OrigTF5'.

The sensitivity analysis showed that attributing burning surfaces to the front and top surfaces of the obstacle results in a greater radiative impact upon the test wall – in particular when the smaller vehicle (smaller burning surface area) is employed. Consequently, the smaller car with burning top and facing surface identified as OrigcarTF5, was chosen as worst case for simulation purposes. For this reason, the same burner configuration was employed for the waste bin simulation. The geometry of the vehicle burner simulated in FDS is depicted in Figure 10.

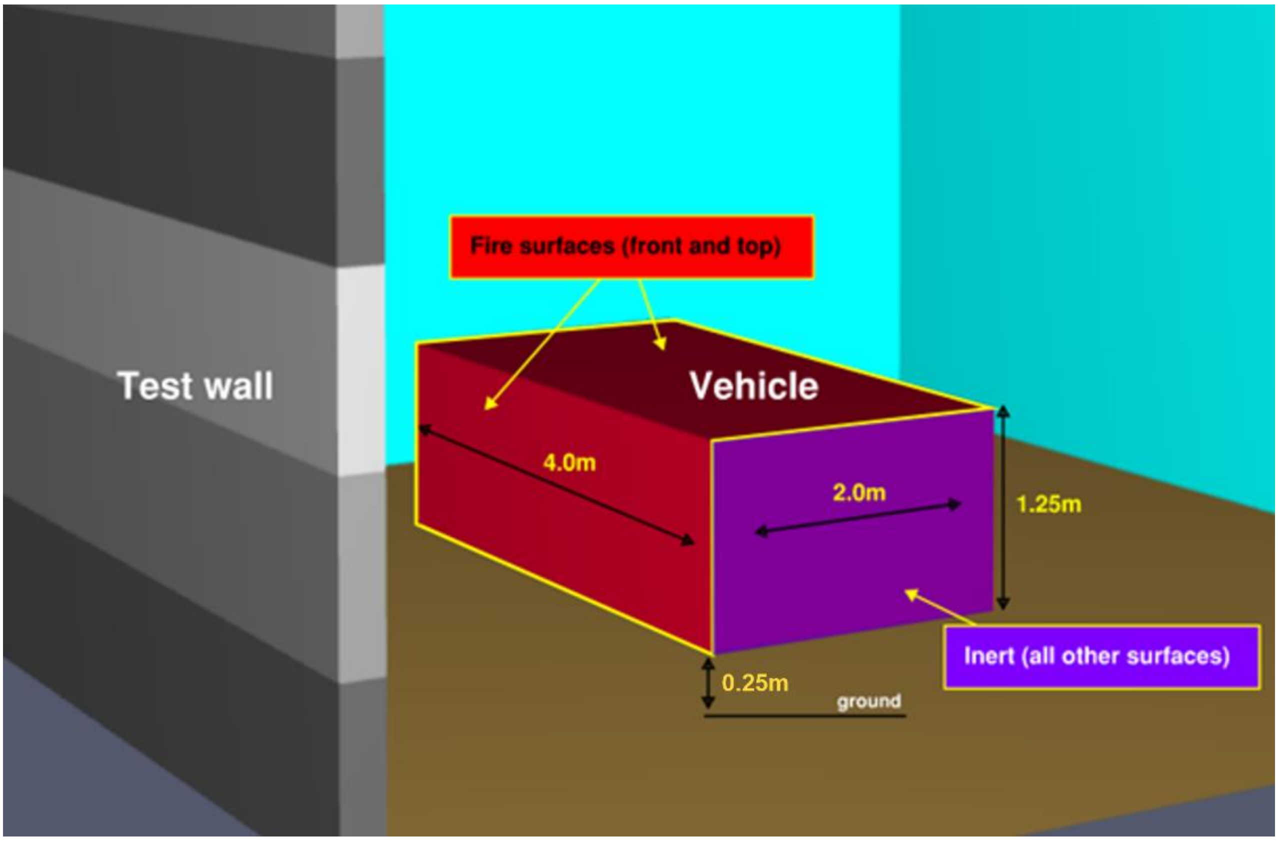


Figure 10: Simulation vehicle burner

5.2.2 Waste bin fire scenario

As indicated in the discussion above on vehicle burner sensitivity, the number and orientation of burning surfaces attributed to the fire obstruction and the orientation influences the level of radiative heat flux impinging on the test wall in both cases. Conservatively, the simulation considered that two individual wheeled container waste bins ignite simultaneously in a single location with a combined HRR of 2MW. The simulation attributed burning surfaces to both the top surface and the front surface (facing the test wall), with remaining surfaces designated inert as highlighted in Figure 11.

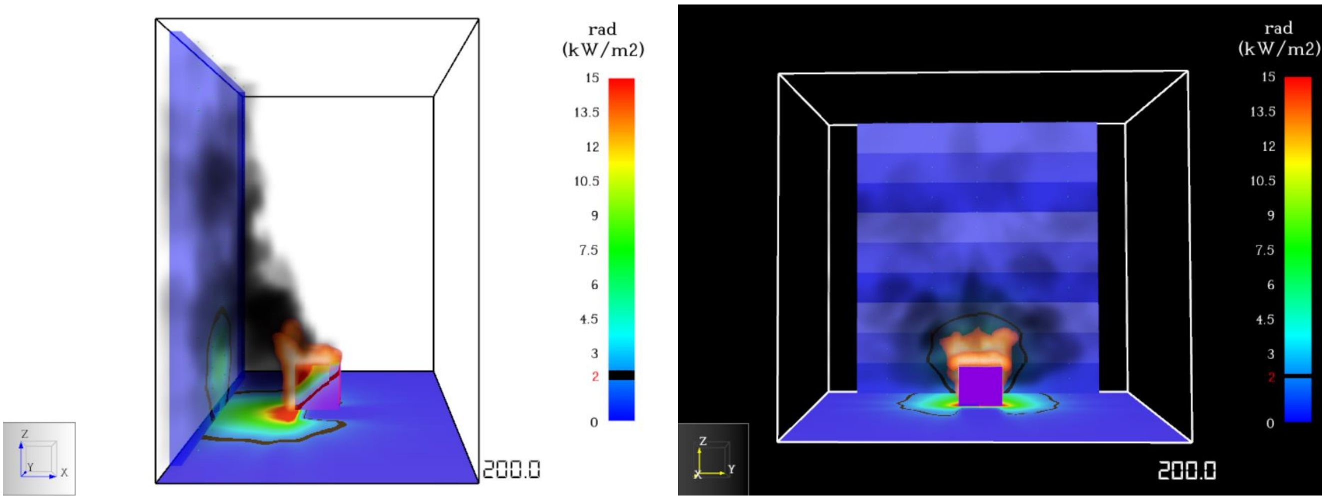


Figure 11: Pyrosim Smokeview visualisation of burning surfaces attributed to the top and front facing surfaces of the wastebin burner

5.2.3 Heat release rate per unit area and dimensions of fire sources

The dimensions of the simulated fire sources and the prescribed heat release rate per unit area (HRRPUA) corresponding to each fire scenario are presented in Table 3.

Table 3: The simulated parameters of car and waste bin fire scenarios

Parameters	**Car fire**	**Waste bin fire**
	5MW	**2MW**
Length (m)	4.0	1.24
Width (m)	2.0	1.07
Height (m)	1.25	1.18
Distance from ground level (m)	0.25	0.20
Burner area (m^2)	13	2.79
HRRPUA (kW/m^2)	384.62	716.85
No. fire source locations	6	4
No. wind speed levels	14	14
No. simulation cases	84	40

5.2.4 Fire Ramp-up

It was conservatively considered that the burner achieves the peak heat release rate from the beginning of the simulation through to the end (as opposed to an approximated and fully synthesised, vehicle fire HRR curve), with results to be reviewed from the earliest timestamp of perceived fire stability (approximating steady state conditions).

5.2.5 Gas phase devices

Radiative heat flux measurement devices are gas phase, located at a distance of 0.125m in the positive x direction (in front of the test wall). These devices are positioned at increments of 1.5m in the y direction (horizontally) and 0.5m in the z direction (vertically) with radiant heat flux outputs assigned for the simulation.

5.2.6 Wind factor

It was noted that the results for worst case simulations show vehicle fires to be the most conservative, where results have shown that the smaller HRR attributed to waste bins resulted in significantly less radiative exposure upon the test wall.

Further investigation into the effects of wind were undertaken, to analyse the impacts that both wind speed and wind direction had on radiative exposure profile on the test wall. A sensitivity analysis of wind direction was performed and presented in section 5.5.3 to identify the most vulnerable wind direction to be considered for the simulations.

The wind data used in the study was from Essendon Airport weather station, however, the same methodology can be applied to other locations with their corresponding historical wind data. The wind speed was recorded on an average of every 30 minutes and the database was used to generate the frequency curve corresponding to different wind speed. A wind shielding factor of 0.85 was used for designing Australian suburban housing following AS 1170.2 [20].

The most common wind speed range is between 0 and 15 m/s (Figure 12). For the simulation, a wind speed range of 0 to 13 m/s with an increment of 1 m/s was chosen after multiplying by the shielding factor of 0.85.

only the worst wind direction was simulated 84 times for car simulation and 40 times for bin simulations".

A total of 84 and 40 simulation cases were conducted for the car fire and bin fire scenarios respectively, taking into account the different locations of the fire source, varying wind speed levels, and at a perpendicular wind direction, identified as most conservative in the sensitivity analysis provided in Section 5.5.3 of the Vehicle fire results.

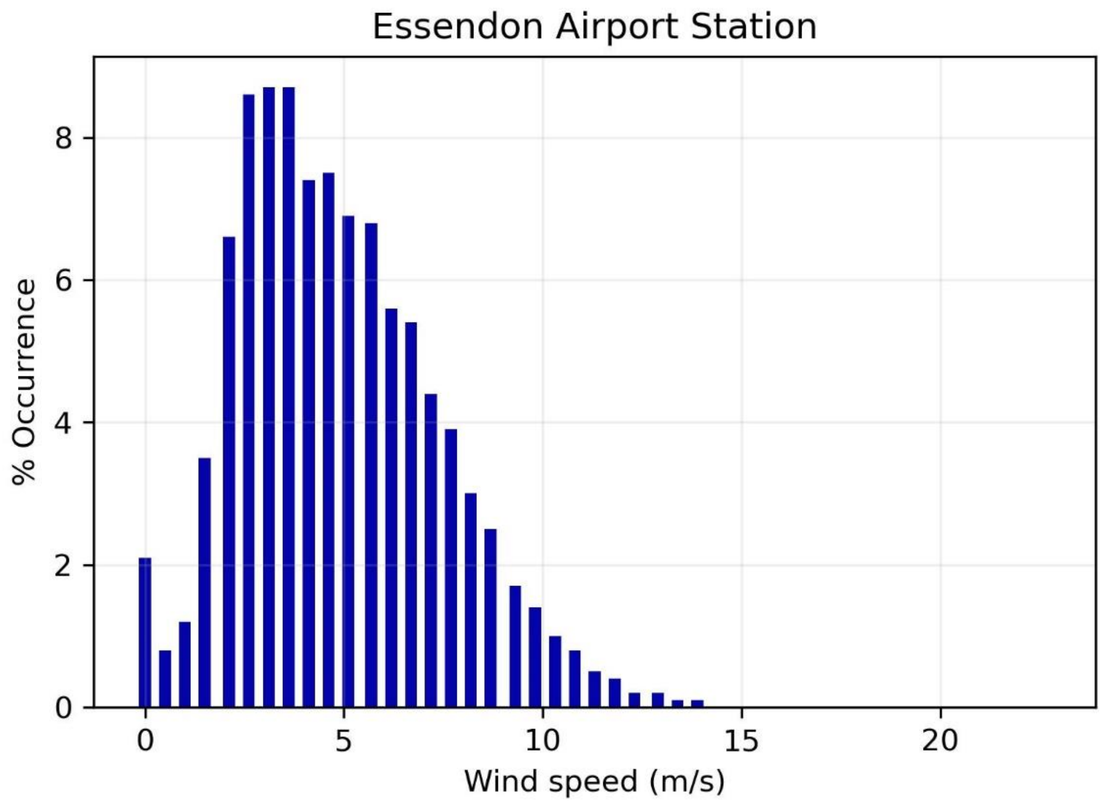


Figure 12: Historical wind data at Essendon Airport station

5.3 Heat flux mapping and safe zone map

Based on the threshold of the cladding ignition test for the flammable polymers contained within EPS and ACP PE, the lowest heat flux that can ignite these two materials was found. From that, heat flux mapping on the facade was constructed using the FDS software. The heat flux mapping is dependent upon the following:

1. The vehicle or waste bin proximity to the test wall (i.e., the distance X from the car bay/waste bin to the facade);
2. External factors such as wind speed and direction; and
3. The combustible cladding material.

In the heat flux map, vulnerable cladding areas for the polymers of EPS and ACP are identified, and a safe zone map constructed (i.e., the vertical and the horizontal distances on the facade that need removal consideration). Figure 13 shows a visual representation of the vertical and horizontal removal distances, defined by the following parameters:

H_{safe} - The safe vertical distance considered for removal due to car or bin fire

Y_{safe} - The is the safe horizontal distance or 'width' considered for removal due to car or bin fire

$Y_{safe\ at\ \mathbf{3m}}$ - The safe horizontal distance or 'width' considered for removal due to car or bin fire at a height of 3m.

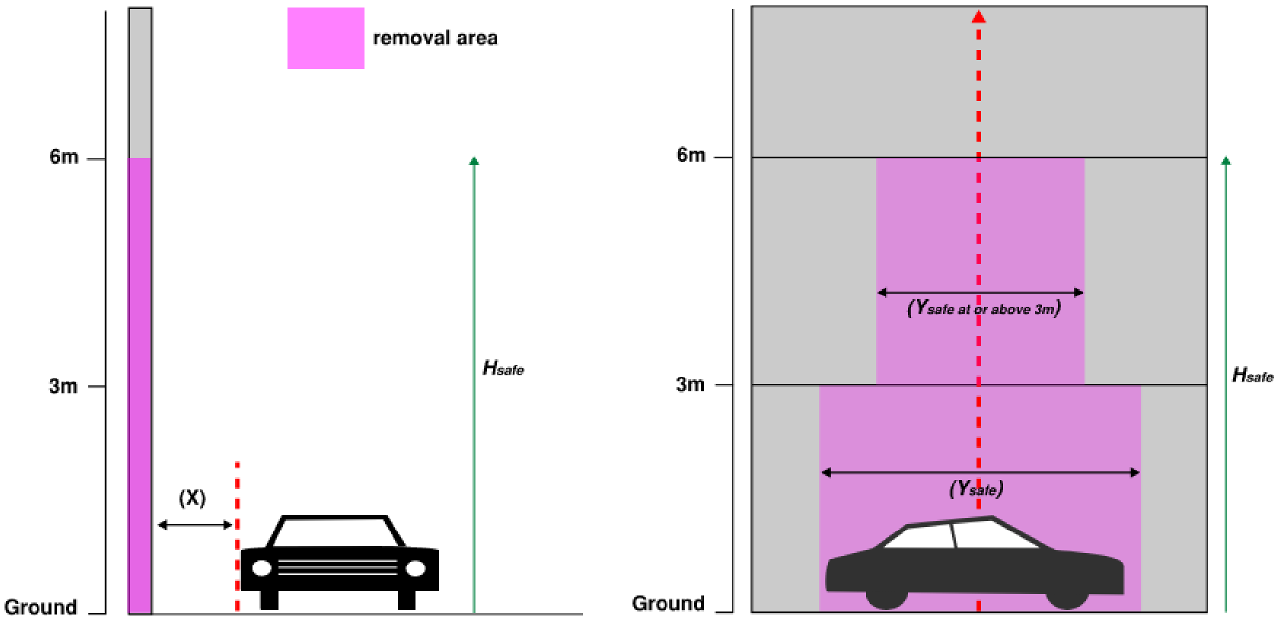
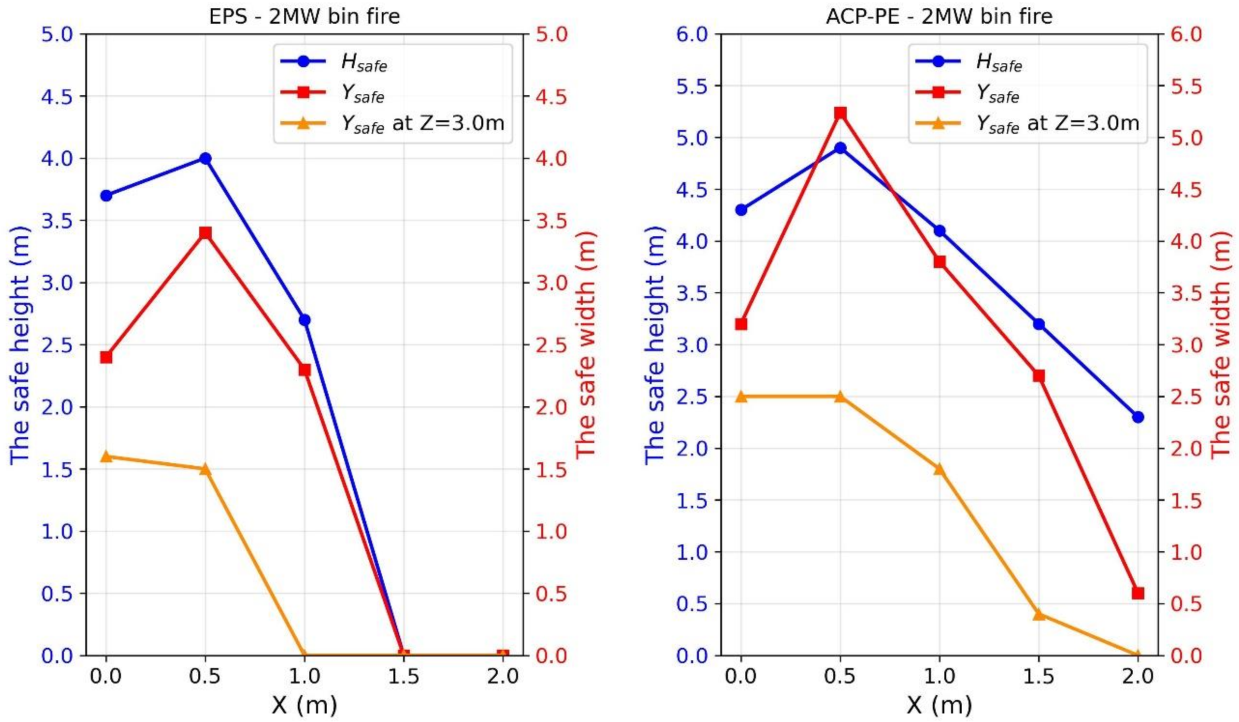


Figure 13: Indicative diagram highlighting the removal area of cladding (pink), corresponding with a vehicle or carparking at distance x, horizontally from walls with combustible cladding installed

The safe zone map is generated by comparing the area with the received heat flux of equal or higher than the critical heat flux determined through the method described in Section 4.1. It is also assumed that there is an equal probability of ignition for any given point exposed to the heat flux higher than the critical value. Considering the practicality of construction, the safe zone was rectangular, and its boundaries were determined by the maximum height and width corresponding to the area above. The height was calculated from the ground floor level (where vehicles are parked or bins are stored) while the widths were calculated based on the typical length of a parking lot vehicles - approximately 5.5m [21]).

5.4 Waste bin results

Following the methodology described above, the results for waste bin fire with fuel load of 2MW is presented in Figure 14, nominating the maximums for EPS and ACP respectively. For evaluation, curves were fitted to the raw 0.5m resolution data and the points read from these fitted curves for following preliminary plots.



(a) (b)

Figure 14: The maximum H_{safe} and Y_{safe} based on waste bin locations in case of 2MW bin fire for (a) EPS cladding, and (b) ACP PE cladding

EPS and ACP PE cladding removal recommendations in the case of 2MW bin fire scenario, regardless of wind speed, are summarised in Table 4.

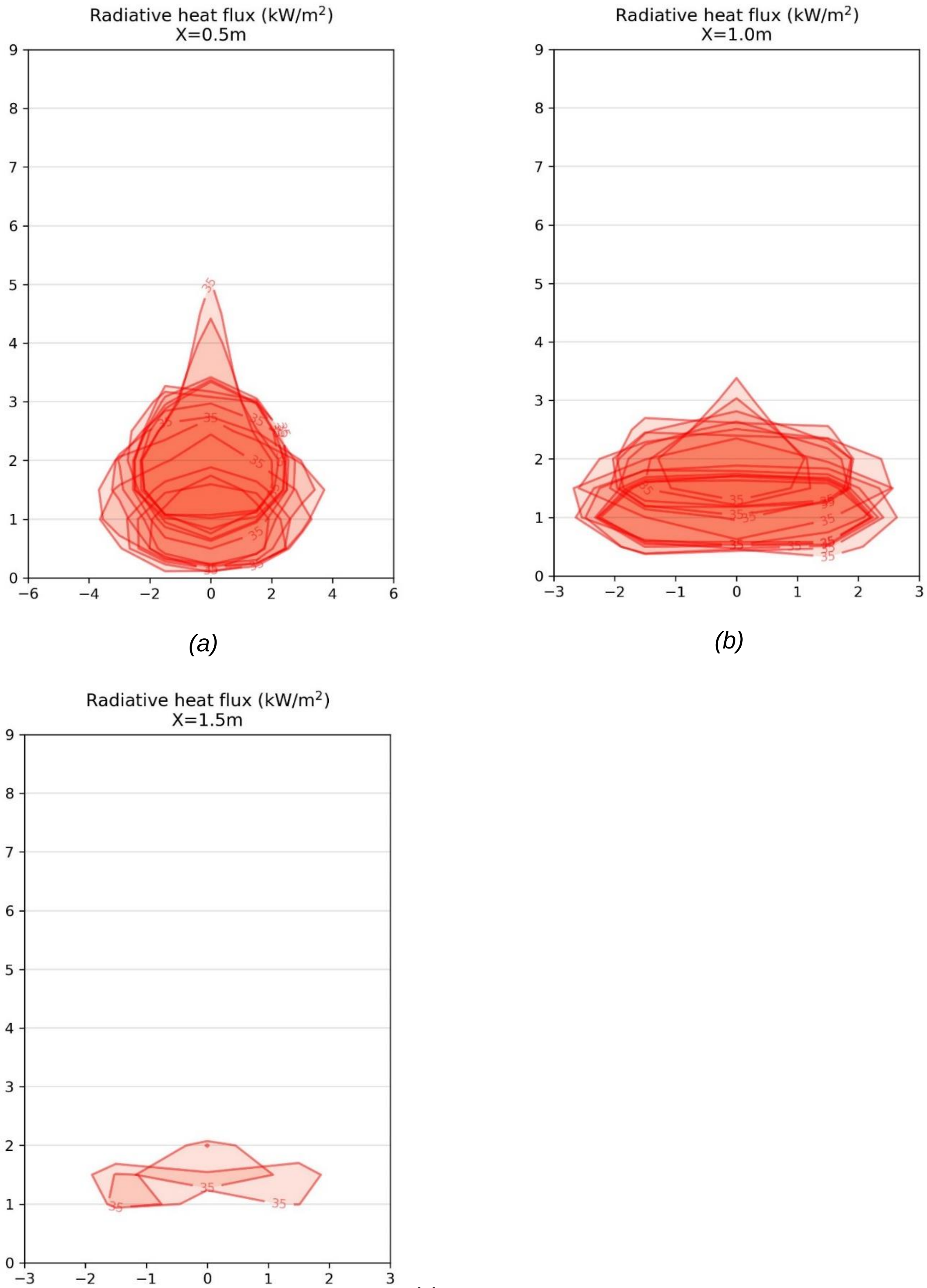
Table 4: H_{safe} and Y_{safe} for EPS and ACP PE cladding in case of 2MW bin fire

X (m)	EPS cladding			ACP PE cladding		
	H_{safe} (m)	Y_{safe} (m)	$Y_{safe, 3.0}$ (m)	H_{safe} (m)	Y_{safe} (m)	$Y_{safe, 3.0}$ (m)
0.0	3.7	2.4	1.6	4.3	3.2	2.5
0.5	4.0	3.4	1.5	4.9	5.2	2.5
1.0	2.7	2.3	0	4.1	3.8	1.8
1.5	0	0	0	3.2	2.7	0.4
2.0	0	0	0	2.3	0.6	0

5.5 Vehicle fire results

5.5.1 EPS cladding

Figure 15 depicts the heat flux map caused by the car fire in relation to the location of the car bay in the case of EPS on the facade. The contours presented in Figure 15a-c correspond to multiple cases with varying wind speed levels.



(c)

Figure 15: The heat flux map of EPS; (a) X = 0.5m (b) X = 1.0m (c) X = 1.5m. X is the distance from the car bay to the cladding surface

Simulation results show that the car fire only affects the EPS cladding within 1.5m away from the facade. At X = 0.5m, the boundary of cladding areas that can be vulnerable to ignition is within 8m wide (-4m to 4m) and 5m high (see Figure 15a). These boundaries are narrowed down to be less than 6m wide (-3m to 3m) and 3.5m high at X = 1.0m (see Figure 15b), and approximately 4m wide (-2m to 2m) and 2.1m high at X = 1.5m (see Figure 15c).

Figure 16 represents the impact of wind speeds ranging from 0 to 13 m/s on the safe height (H_{safe}) and the safe width (Y_{safe}). It should be noted that the result in Figure 16 account for the impact of the 5.5m-wide car bay on the calculation of Y_{safe}. The affected cladding areas expressed in Figure 15 only take into account one car fire position in the centre of the car bay.

While H_{safe} is calculated from the highest point on each contour curve (maximum z-coordinate), the Y_{safe} formulation is expressed as follows:

$$Y_{safe} = W_{car\ bay} + (|Y_{min}| - L_{car}/2) + (Y_{max} - L_{car}/2) \quad (4)$$

Where:

- $W_{car\ bay}$ is the car bay width, 5.5m
- L_{car} is the car length, 4.0m
- Y_{min} is the minimum y-coordinate of the contour curve
- Y_{max} is the maximum y-coordinate of the contour curve
- Y_{min} *and* Y_{max} are calculated from the car bay centre

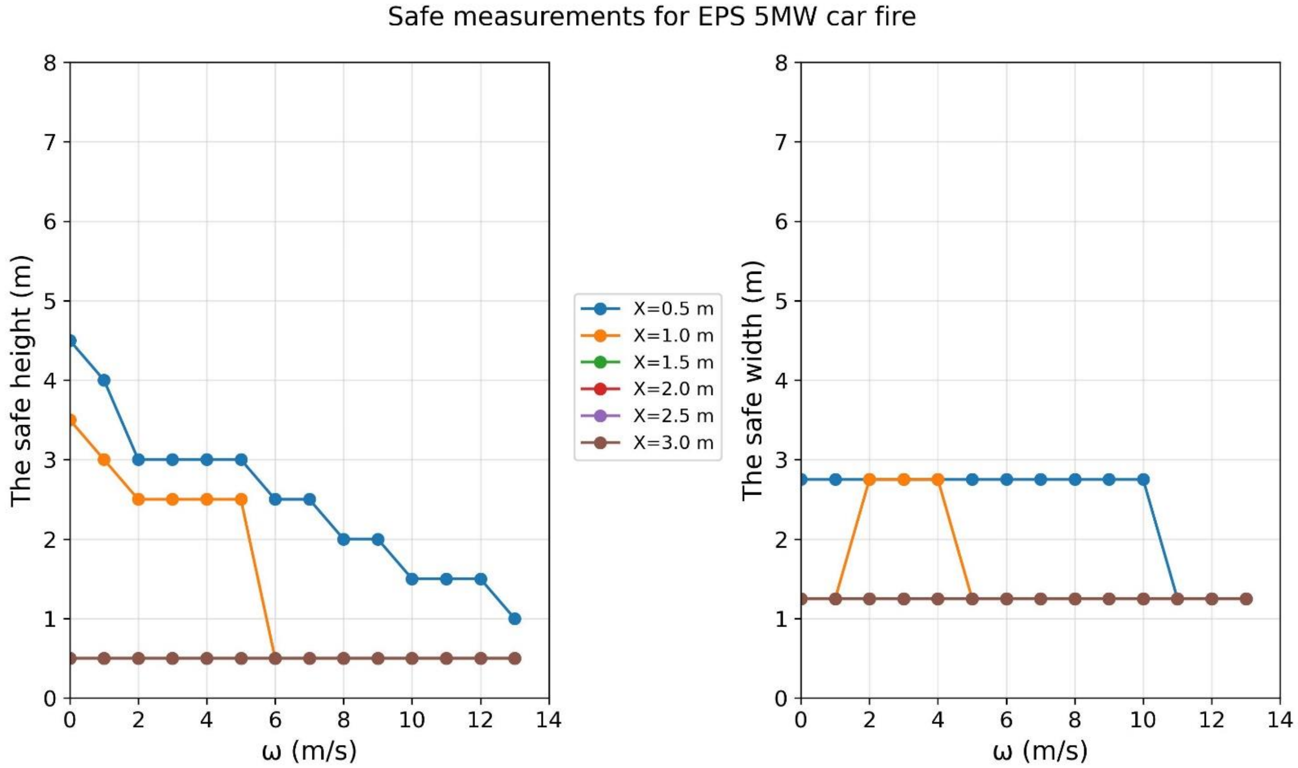


Figure 16: H_{safe} and Y_{safe} based on vehicle locations and wind speed levels when cladding material is EPS

H_{safe} reaches its peak at 4.5m and 3.5m in the case of 0 m/s wind speed at X = 0.5m and X = 1.0m, respectively. H_{safe} remains at 0.5m within the distance range of X = 1.5-3.0m, regardless of the wind speed levels. Meanwhile, at X = 0.5m and X = 1.0m, Y_{safe} has a maximum value of 2.75m. The Y_{safe} values remain constant at 1.25m when X = 1.5-3.0m, regardless of the wind speed levels. In general, the presence of perpendicular wind tends to inhibit the vertical and horizontal spread of flames induced by a car fire within a distance range of 0.5-1.0m. Beyond that range, which is from

1.5m to 3.0m away from EPS cladding, the wind appears to have no impact on changing the affected area on EPS cladding surface (see Figure 17).

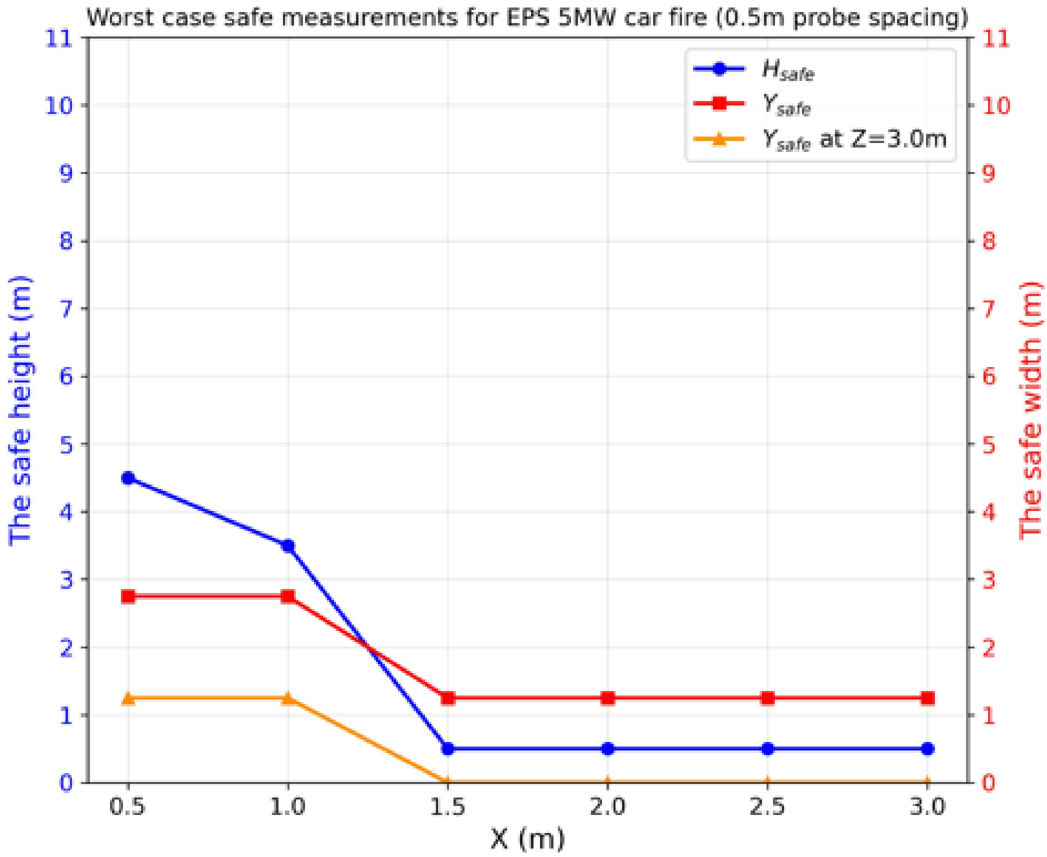


Figure 17: The maximum H_{safe} and Y_{safe} based on vehicle locations when cladding material is EPS

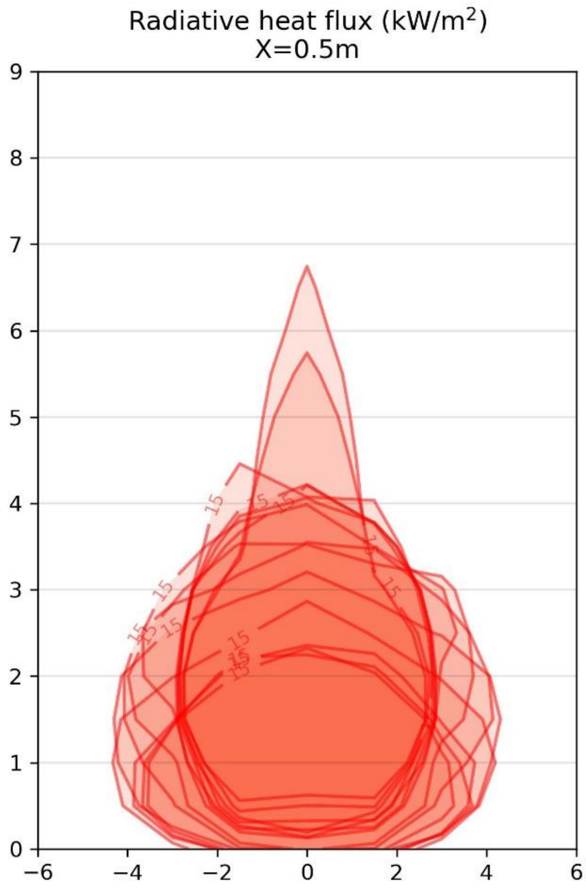
The maximum values of H_{safe} and Y_{safe} versus the car fire location in the case of EPS cladding, regardless of wind speed, are expressed in Figure 17. It is summarised as follows:

- At X = 0.5m, H_{safe} = 4.5m, and Y_{safe} = 2.75m
- At X = 1.0m, H_{safe} = 3.5m, and Y_{safe} = 2.75m
- At X = 1.5m, Hsafe = 0.5m, and Ysafe = 1.25m
- At X = 2.0m, Hsafe = 0.5m, and Ysafe = 1.25m
- At X = 2.5m, Hsafe = 0.5m, and Ysafe = 1.25m
- At X = 3.0m, H_{safe} = 0.5m, and Y_{safe} = 1.25m

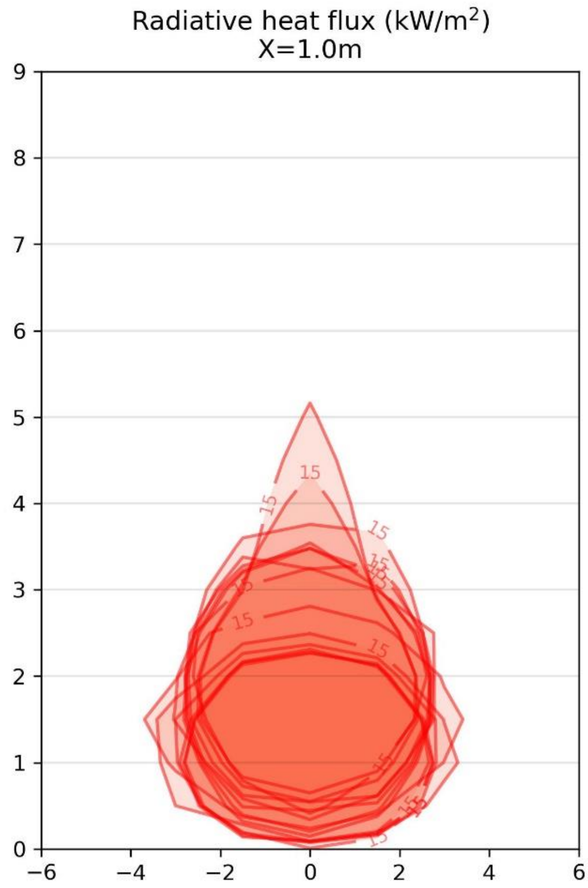
5.5.2 ACP PE cladding

The heat flux map caused by the car fire in relation to the location of the car bay in the case of ACP PE on the facade is presented in Figure 14. Because the minimum heat flux to ignite PE is 15 kW/m^2 compared to 35 kW/m^2 for EPS, this case is more severe than the case of EPS cladding. The simulation results show that the car fire still has a potential impact on PE cladding at the location of 2.5m away from the facade.

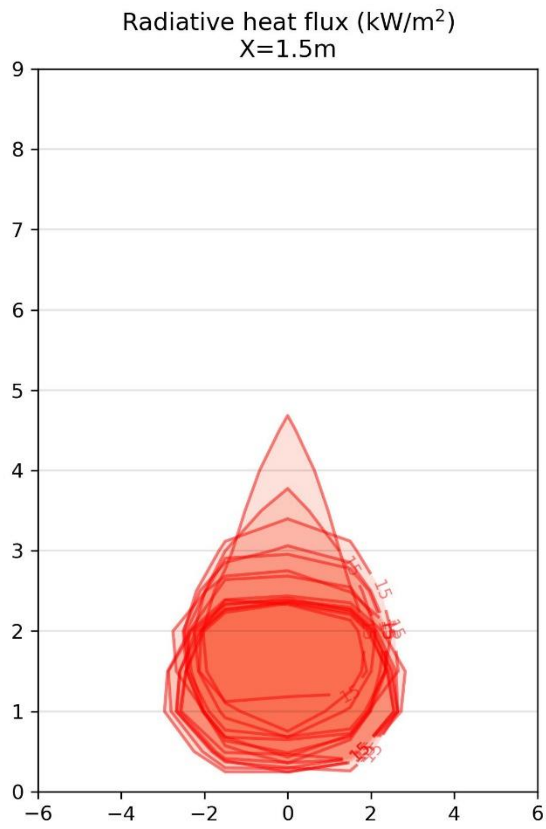
At X = 0.5m, the vulnerable area to ignite PE cladding is within 9m wide (-4.3m to 4.3m) and 6.7m high (see Figure 17a). These boundaries are narrowed down to be around 7m wide (-3.5m to 3.5m) and 5.2m high at X = 1.0m (see Figure 17b), approximately 6m wide (-3m to 3m) and 4.7m high at X = 1.5m (see Figure 17c), 5m wide (-2.5m to 2.5m) and 3.9m high at X = 2.0m (see Figure 17d), and around 2m wide (-1m to 1m) and 2.8m-high at X = 2.5m (see Figure 17e).


Radiative heat flux (kW/m2)
X=0.5m
15

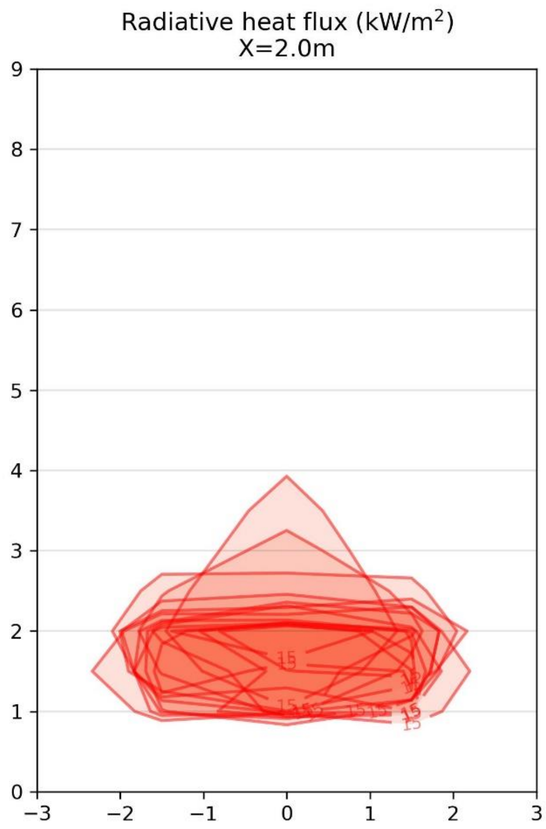
(a)


Radiative heat flux (kW/m2)
X=1.0m
15

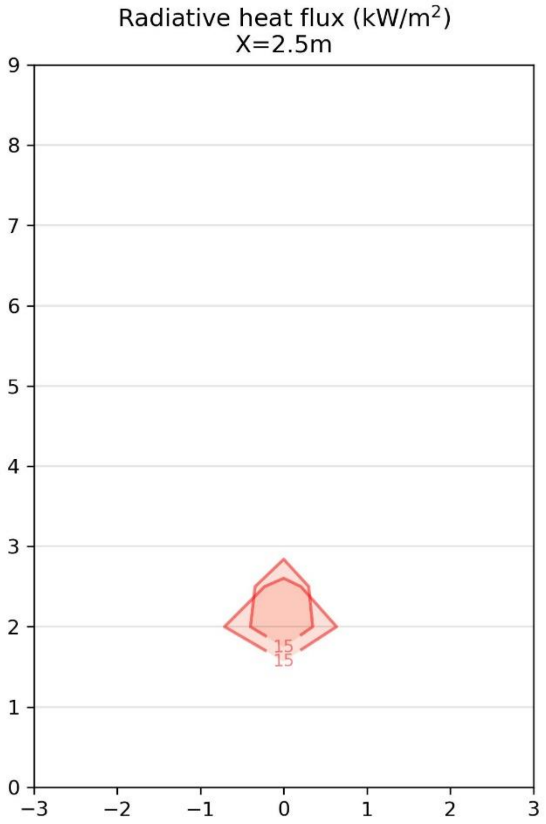
(b)


Radiative heat flux (kW/m2)
X=1.5m
15

(c)


Radiative heat flux (kW/m2)
X=2.0m
15

(d)



(e)

Figure 18: The heat flux map of PE; (a) X = 0.5m (b) X = 1.0m (c) X = 1.5m (d) X = 2.0m (e) X = 2.5m. X is the distance from the car bay to the cladding surface

Figure 19 illustrates the influence of wind speed intensity on the values of H_{safe} and Y_{safe}, with consideration of the car bay (5.5m wide) in the calculation of Y_{safe}. In the simulation of ACP PE cladding, H_{safe} reaches its maximum value when there is no wind occurrence, except for the cases of X = 2.5m and X = 3.0m.

These maximum safe height (H_{safe}) values occurring at a windspeed of 0m/s are H_{safe} = 6.0m at X = 0.5m, H_{safe} = 4.5m at X = 1.0m, H_{safe} = 4.0m at X = 1.5m, and H_{safe} = 3.5m at X = 2.0m. When the car fire occurs at 2.5m from the cladding, H_{safe} reaches its peak at 2.5m when the wind velocity is 1 m/s. H_{safe} remains at 0.5m when X = 3.0m, regardless of the wind speed levels. At X = 0.5m, Y_{safe} reaches its maximum value of 4.25m for the wind speeds between 8 m/s and 10 m/s. When the car fire happens within the range of 1.0-2.0m away from the ACP PE cladding, the maximum values of Y_{safe} are 2.75m. Also, regardless of the levels of wind speed, Y_{safe} remains constant at 1.25m for X = 2.5m and 3.0m.

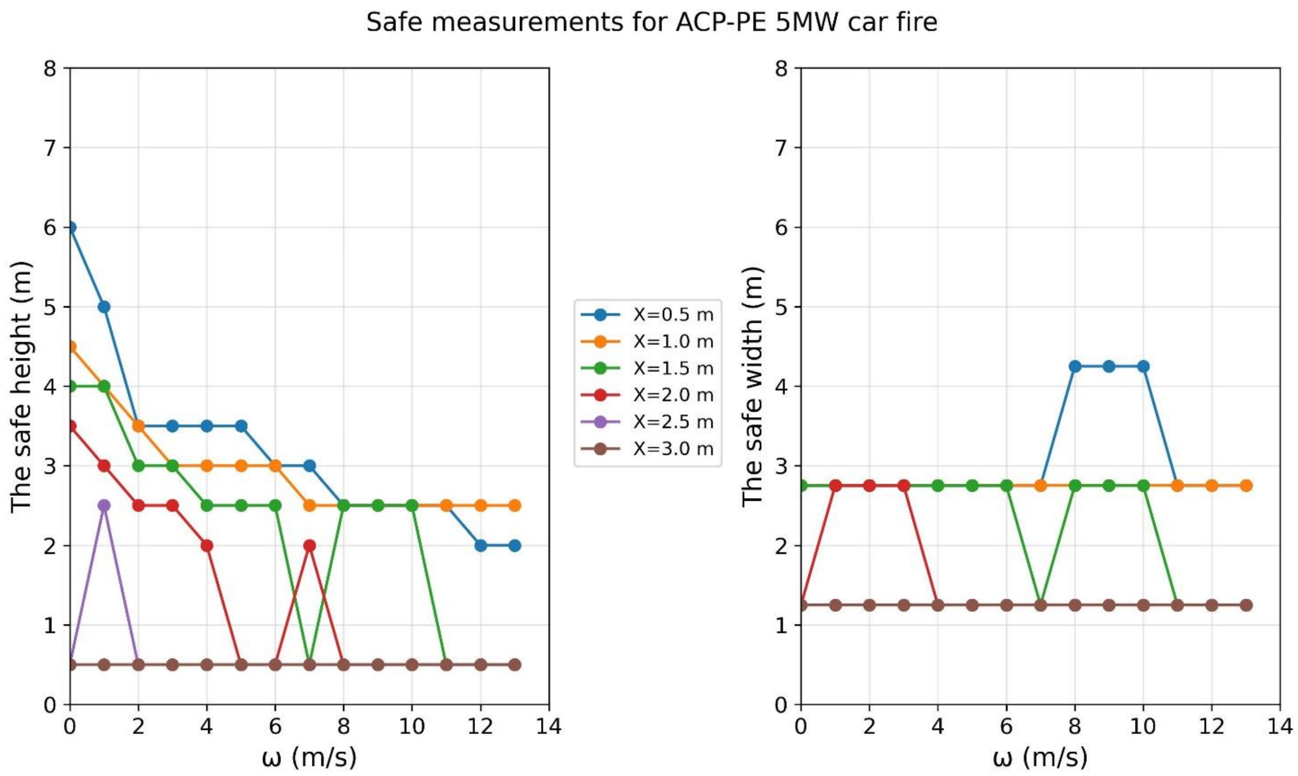


Figure 19: Hsafe and Ysafe based on vehicle locations and wind speed levels when cladding material is PE

The maximum values of H_{safe} and Y_{safe} versus the car fire location in the case of ACP PE cladding, regardless of wind speed, are expressed in Figure 20. It is concluded as follows:

- At X = 0.5m, H_{safe} = 6.0m, and Y_{safe} = 4.25m
- At X = 1.0m, H_{safe} = 4.5m, and Y_{safe} = 2.75m
- At X = 1.5m, H_{safe} = 4.0m, and Y_{safe} = 2.75m
- At X = 2.0m, H_{safe} = 3.5m, and Y_{safe} = 2.75m
- At X = 2.5m, H_{safe} = 2.5m, and Y_{safe} = 1.25m
- At X = 3.0m, H_{safe} = 0.5m, and Y_{safe} = 1.25m

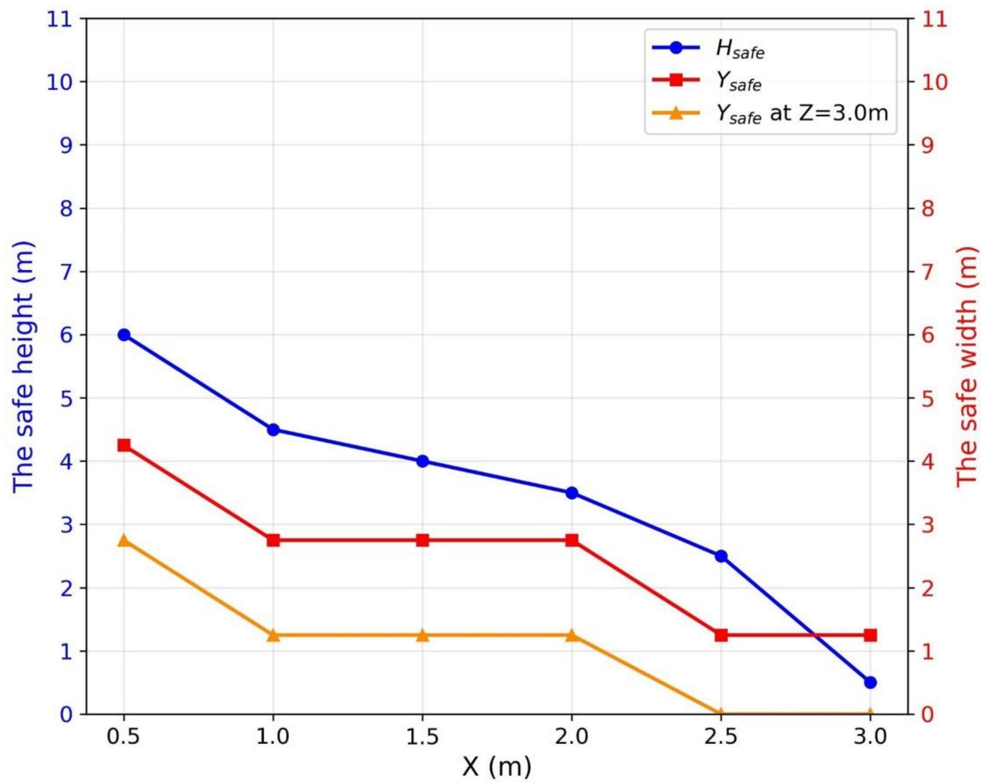


Figure 20: The maximum Hsafe and Ysafe based on vehicle locations when cladding material is ACP PE

When considering the 'teardrop'-shaped patterns observed in the heat flux maps shown in Figure 15 and Figure 18 for EPS and ACP PE claddings, it is strongly recommended to include the required width of cladding for removal at Z = 3.0m (Y_{safe} at Z = 3.0m) as a potential cost-saving measure, rather than opting for the Y_{safe} value along the entire height for cladding removal. The rules defined for the removal of EPS and ACP PE claddings in the case of 5MW car fire scenario, regardless of wind speed, are summarised in Table 5 below.

Table 5: H_{safe} and Y_{safe} for EPS and ACP PE cladding in case of 5MW vehicle fire

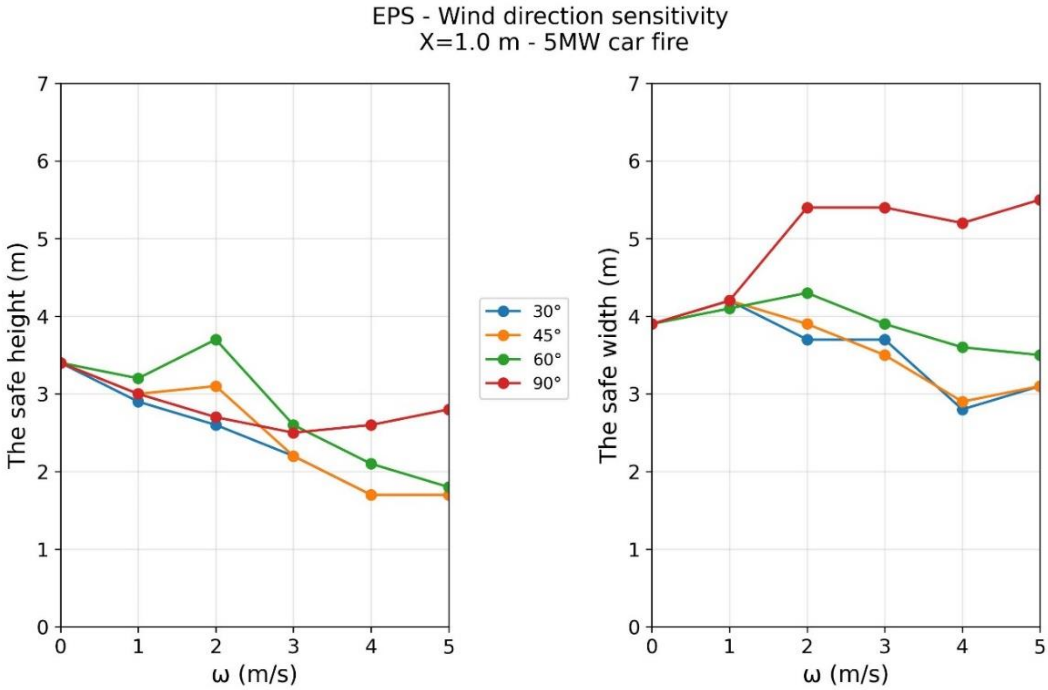
X (m)	EPS cladding			ACP PE cladding		
	H_{safe} (m)	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**	**H_{safe} (m)**	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**
0.5	4.5	2.75	1.25	6.0	4.25	2.75
1.0	3.5	2.75	1.25	4.5	2.75	1.25
1.5	0.5	1.25	0.0	4.0	2.75	1.25
2.0	0.5	1.25	0.0	3.5	2.75	1.25
2.5	0.5	1.25	0.0	2.5	1.25	0.0
3.0	0.5	1.25	0.0	0.5	1.25	0.0

Where:

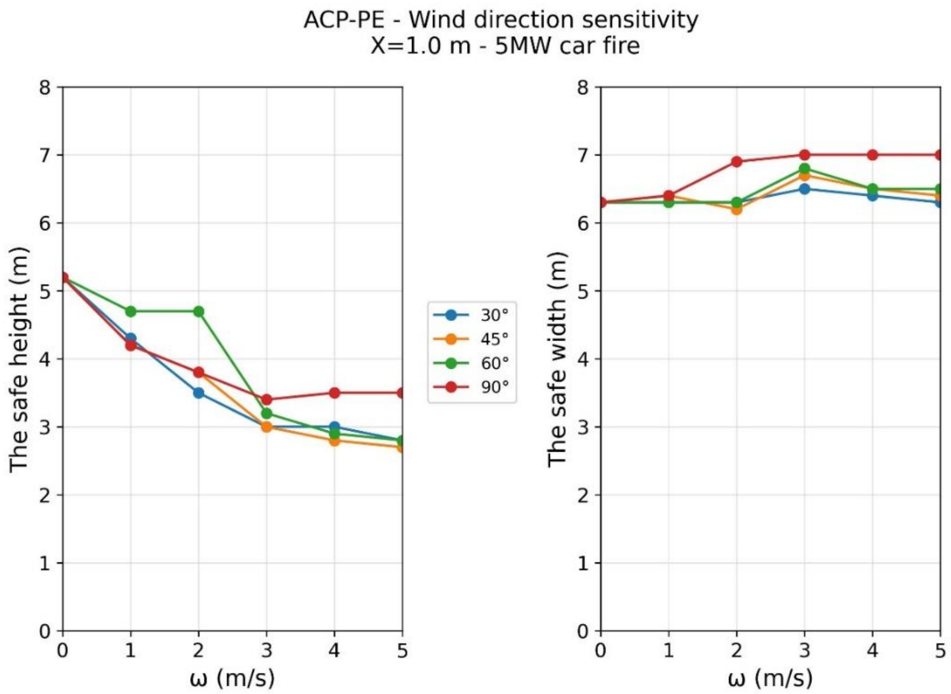
- *X* is the distance between the combustible cladding and the external fire source (m) where they are the closest;
- H_{safe} is the required height of cladding to be removed from the ground level (m);
- Y_{safe} is the required width of cladding to be removed when the height from the ground level is less than 3m (m); and
- $Y_{safe, 3.0}$ is the required width of cladding to be removed when the height from the ground level is 3m or more (m).

5.5.3 Sensitivity analysis of wind direction

The effect of wind direction on the facade affected by a car fire was also analysed in the study. In this analysis, the distance from the car bay to the facade was fixed at 1m. In order to save computational costs, the wind speed was limited in the range from 0 to 5 m/s. The wind direction domain gradually shifts in 30º, 45º, 60º, and 90º. It can be seen from Figure 21 that while the wind parameters have a marginal impact on H_{safe} values, the case with the perpendicular wind to the facade (90º) provides higher values of Y_{safe} compared to the cases with the diagonal wind (see Figure 21). It can be concluded that a conservative approach was taken with the consideration of perpendicular wind for the car fire simulations.



(a)



(b)

Figure 21: Hsafe and Ysafe based on wind direction and wind speed levels at X = 1.0m (a) EPS (b) ACP PE

6 Concluding remarks

The aboslute and explicit measurements pertaining to the removal of EPS and ACP PE cladding in the case of 5MW car fire scenario, regardless of wind speed, are summarised in Table 6.

Table 6: H_{safe} and Y_{safe} for EPS and ACP PE cladding in case of 5MW car fire

X (m)	**EPS cladding**			**ACP PE cladding**		
	H_{safe} (m)	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**	**H_{safe} (m)**	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**
0.5	4.5	2.75	1.25	6.0	4.25	2.75
1.0	3.5	2.75	1.25	4.5	2.75	1.25
1.5	0.5	1.25	0.0	4.0	2.75	1.25
2.0	0.5	1.25	0.0	3.5	2.75	1.25
2.5	0.5	1.25	0.0	2.5	1.25	0.0
3.0	0.5	1.25	0.0	0.5	1.25	0.0

Where:

- *X* is the distance between the combustible cladding and the external fire source (m) where they are the closest;
- H_{safe} is the required height of cladding to be removed from the ground level (m);
- Y_{safe} is the required width of cladding to be removed when the height from the ground level is less than 3m (m);
- $Y_{safe, 3.0}$ is the required width of cladding to be removed when the height from the ground level is 3m or more (m).

Noted that the midpoint of Y_{safe} *and* $Y_{safe, 3.0}$ coincides with the centre of the designated area of the external fire source. For example, to determine the total width of the cladding to be removed, measure a distance of $Y_{safe}/2$ to the left and right from the centre of the designated area of the external fire source.

The results serve as a knowledge base for cladding removal and should be considered in context of genuine scenarios observed in the built environment.

The aboslute and explicit measurements pertaining to the removal of EPS and ACP PE cladding in the case of 2MW bin fire scenario, regardless of wind speed, are summarised in Table **7**.

Table 7: Hsafe and Ysafe for EPS and ACP PE cladding in case of 2MW waste bin fire

X (m)	**EPS cladding**			**ACP PE cladding**		
	H_{safe} (m)	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**	**H_{safe} (m)**	**Y_{safe} (m)**	**$Y_{safe, 3.0}$ (m)**
0.5	4.0	3.4	1.5	4.9	5.2	2.5
1.0	2.7	2.3	0	4.1	3.8	1.8
1.5	0	0	0	3.2	2.7	0.4
2.0	0	0	0	2.3	0.6	0

6.1 Practical approach and implementation

6.1.1 Car parking proximal combustible cladding

ACP PE

The analysis supports that where designated carparks are located less than **3m horizontally away** from installed ACP, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **2.25m away** horizontally from installed ACP, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

EPS

The analysis supports that where designated carparks are located less than **2m horizontally away** from installed EPS, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **1.25m away** horizontally from installed EPS, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

Carpark removal

An approach that involves retaining the combustible cladding but removing or blocking parking areas can be implemented to achieve the intent of safe distances for EPS and ACP PE highlighted above.

6.1.2 Wastebins proximal combustible cladding

ACP PE

The analysis supports that where designated wastebin areas are located less than **3m horizontally away** from installed ACP, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **1.75m away** horizontally from installed ACP, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

EPS

The analysis supports that where designated carparks are located less than **1.5m horizontally away** from installed EPS, removal options should be explored as a mechanism for risk reduction from the **ground level to a height of 3m**. Additionally, where designated carparking is less than **1m away** horizontally from installed EPS, the removal option should consider **both ground and level 1 to a minimum height of 6m** for removal.

Designated wastebin area removal or relocation

An approach that involves retaining the combustible cladding but removing or relocating designated bin areas can be implemented, provided it achieves the intent of safe distances for EPS and ACP PE highlighted above.

7 References

[1] T. Korhonen and J. Hietaniemi, "Fire safety of wooden façades in residential suburb multi-storey buildings," VTT Building and Transport, Finland, 2005.

[2] J. Anderson, R. McNamee, L. Boström and B. Milovanović, "Modeling of fire exposure in facade fire testing," Fire and Materials, vol. 42, no. 5, pp. 475-483, 2018.

[3] J. A. Anderson, R. McNamee, L. Boström and B. Milovanović, "Experimental comparisons in façade fire testing considering SP Fire 105 and the BS 8414-1," Fire and Materials, vol. 42, no. 5, pp. 484-492, 2018.

[4] R. Jansson and J. Anderson, "Experimental and numerical investigation of fire dynamics in a façade test rig," in Proceedings of fire computer modeling, Santander, Spain, 2012.

[5] G. Jensen, "Fire spread modes and performance of fire stops in vented façade constructions–overview and standardization of test methods," in MATEC Web of Conferences, EDP Sciences, 2013.

[6] F. Ren, L. Hu, X. Sun and K. Hu, "An experimental study on vertical temperature profile of facade fire plume ejected from compartment with an opening subjected to external wind normal to facade," International Journal of Thermal Sciences, vol. 130, pp. 94-99, 2018.

[7] G. Bytskov, "Numerical simulation of fire performance and test conditions for facade insulation materials," 2015.

[8] S. Chauhan, "Investigation on automobile fire and its root causes," in Computational and Experimental Methods in Mechanical Engineering. Smart Innovation, Systems adn Technologies, vol. 239, Singapore, Springer, 2022.

[9] "Fire in the United States 2008-2017," U.S. Fire Administration, Emmitsburg, 2019.

[10] EV Firesafe, "Passenger EV LIB (electric vehicle, lithium-ion battery) fire incidents; June 2023 statistics release and EV type comparison," EVFiresafe, June 2023. [Online]. Available: https://www.evfiresafe.com/ev-battery-fire-overview. [Accessed 10 December 2023].

[11] D. Macneil, G. Lougheed, C. Lam, G. Carbonneau, R. Kroeker, D. Edwards, J. Tompkins and G. Lalime, "Electric vehicle fire testing.," in Presentation to the 8th EVS-GTR meeting, Washington, 2015.

[12] A. Lecocq, M. Bertana, B. Truchot, Marlair and G, " Comparison of the fire consequences of an electric vehicle and an internal combustion engine vehicle URL https://www.scipedia.co," in Collection of open conferences in research transport Vol. 2012, 141, 2012.

[13] M. Cheong, M. Spearpoint and C. Fleischmann, "Design fires for vehicles in road tunnels," in 7th International Conference on Performance-Based Codes and Fire Safety Design Methods, 2008.

[14] National Fire Protection Association, "NFPA 502, Standard for road tunnels, bridges, and other limited access highways," NFPA, Quincy , 2011.

[15] The Highways Agency , "BD 78/99 - Design manual for roads and bridges," The Highways Agency, 1999.

[16] Technical Committee 5 Road Tunnels, "Fire and Smoke Control in Road Tunnels," PIARC, 1999.

[17] British Standards Institute, "BS 5906: 2005 Waste Management in Buildings–Code of Practice," British Standards Institute, London, 2005.

[18] International Organization for Standardization, "ISO 5660-1: 2015 Reaction-to-Fire Tests—Heat Release, Smoke Production and Mass Loss Rate—Part 1: Heat Release Rate (Cone Calorimeter Method) and Smoke Production Rate (Dynamic Measurement)," International Organization for Standardization, Geneva, 2015.

[19] K. McGrattan, R. McDermott, C. Weinschenk and G. Forney, “Fire dynamics simulator, user’s guide (version 6),” National Institute of Standards and Technology, 2013.

[20] Standards Australia and Standards New Zealand, “AS/NZS 1170.2: 2011 Structural design actions-Part 2: Wind actions,” Standards Australia and Standards New Zealand, 2011.

[21] Standards Australia/Standards New Zealand , “AS/NZS 2890.1:2004 Parking facilities—Part 1: Off-street car parking,” 2001.

8 Appendices

8.1 Appendix A – PMCR document set and flow