Protocols for Mitigating Cladding Risk Support Package

D.05 – Sprinkler Protection

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.

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Abbreviations

Term	Meaning
ACP-PE	Aluminium Composite Panel with a Polyethylene Core
BOWS	Building Occupant Warning System
CRMF	Cladding Risk Mitigation Framework
CSV	Cladding Safety Victoria
EPS	Expanded Polystyrene
FDS	Fire Dynamics Simulator
PMCR	Protocols for Mitigating Cladding Risk
SOU	Sole Occupancy Unit

1 Background

With respect to fire incidents, injuries and fatalities; buildings with sprinkler systems installed have, inherently, a lower risk associated with them, both with regards to the extent of fire damage from a fire, as well as the level (severity) of injuries and the number of fatalities expected from any fire. It is important to not lose sight of this when we are assessing the impact that combustible cladding may have on/in a sprinkler protected building.

This document sets out the background information which assisted in forming the policy position on buildings with combustible cladding that also have sprinkler systems installed. This work focuses on:

- The relative cladding risk in a sprinkler protected building compared to a general fire risk in the residential building cohort; and
- The relative cladding risk in a sprinkler protected building compared to other buildings in the elevated risk category that was/are not sprinkler protected.

In this document, the terms “sprinkler protected buildings” and “sprinkled buildings” are used for those equipped with automatic sprinklers within SOUs.

2 Eligibility criteria

This document is written on the background that the subject buildings have sprinkler systems installed in accordance with AS 2118.1, AS 2118.4 or AS 2118.6, and where activation of the sprinkler system initiates the general fire alarm conditions or Building Occupant Warning system.

Buildings that have FPAA 101D and FPAA 101H automatic fire sprinkler systems installed are also seen to be provide significant level of suppression, lower injury and fatality benefits as applied up to 25 metres and should be considered as one of the options for interventions to mitigate cladding fire risks.

3 Sprinkler systems in general

3.1 Intent of sprinkler protection

For the purposes of this document, the intent of the sprinklers where they are installed:

1. internally are to:
   a. Control or extinguish a fire before it impinges upon cladding;
   b. Activate the Building Occupant Warning System (BOWS) and General Fire Alarm (GFA) via flow switch or better;
   c. Control or extinguish a fire that enters a Sole Occupancy Unit (SOU) from an external fire (cladding fire, balcony fire).
2. externally are to:
   a. Control or extinguish a fire to mitigate the fire from involving the cladding;
   b. Activate the BOWS and GFA via flow switch or better;
   c. Control or extinguish fire spreading on ignited cladding (where applicable).

3.2 Efficacy

It is considered that an automatic sprinkler system will in most cases either extinguish or control a fire. Statistical data suggests that where pyrolysis persists, it is considered a conservative assumption that a fire will be kept to a constant burning rate and control or cap a fires heat release rate in instances of sprinkler activation [1]. By sprinklers actively capping or controlling the energy released by a fire, it is logical to assume that fire severity is decreased. For the purposes of fire dynamic calculations and modelling for example, reductions in parameters such as flame temperature and emissivity would be considered appropriate and permissible for sprinkler protected areas [2].

3.3 Reliability and effectiveness

Research conducted in the US by the NFPA [3] concluded that where wet pipe sprinkler systems were installed in apartment buildings, the sprinklers operated in 95% of structure fire scenarios. It was also concluded that upon activation, sprinklers were effective in controlling and supressing the fire in 92% of cases.

Statistically, it is indicated that sprinklers are able to maintain or increase the egress tenability levels for occupants and fire brigade, in addition to providing effective property protection. The degree to which sprinklers are effective is closely related to both the robustness of the sprinkler installation and the level of maintenance afforded by the system. Figure 1 and Figure 2 demonstrates the variation in sprinkler effectiveness across various independent studies internationally and the reasons for sprinkler system failure respectively [4].

Source	Country	Data collected from years	Building population/location	Number of events	Nominal reported effectiveness
(Tryon and McKinnon 1969)	US	1897-1924	United States	32778	95.8%
(Tryon and McKinnon 1969)	US	1925-1964	United States	75290	96.2%
(Hall 2006)	US	1999-2002	NFIRS 5.0 data	Not Reported	89%
(Hall 2007)	US	2002-2004	NFIRS 5.0 data	Not Reported	90%
(Hall 2010)	US	2003-2007	NFIRS 5.0 data	44310	91%
(Hall 2012)	US	2006-2010	NFIRS 5.0 data	47520	88%
(US Department of Energy 2004)	US	1955-2003	US DOE facilities	251	98.8%
(Miller 1974)	US	1970-1972	FM insured properties	1355	85%
(Powers 1979)	US	1969-1978	City of New York	5709	97.0%
(Taylor 1990)	US	1982-1986	US general office buildings	6400 per year*	81.3%
(Linder 1993)	US	1988-1993	Industrial Risk Insurers	3446	94.9%
(Baldwin and North 1971)	UK	1967-1968	UK fire brigade data	619	94%
(Marryatt 1988)	Aus/NZ	1886-1986	Australia/New Zealand	9022	99.5%
(Frank et al. 2012)	NZ	2001-2010	New Zealand	1171	86%
(Juneja 2004)	Canada	1995-2002	Ontario Fire Marshal data	2536	70.1%

* Estimated.

Figure 1: Sprinkler Effectiveness - Reprinted - Frank et al.: A review of sprinkler effectiveness studies, Fire Science reviews 2013 2:6

Source	Years	Types of systems	Number of fires	Percent effective	System shut off	Inappropriate system	Lack of maintenance	Manual intervention	Damaged component	System frozen
(Tryon and McKinnon 1969)	1925-1964	Not specified	75290	96.2%	63%	15%	15%		3%	2%
(Hall 2006)	1999-2002	All sprinklers	Not reported	89.3%	65%	5%	11%	16%	3%	
(Hall 2007)	2002-2004	All sprinklers	Not reported	90%	66%	10%	10%	20%	2%	
(Hall 2010)	2003-2007	All sprinklers	44310	91%	53%	20%	15%	9%	2%	
(Hall 2012)	2006-2010	All sprinklers	47520	88%	63%	5%	6%	18%	8%	
(US Department of Energy 2004)	1955-2003	Water-based	251	98.8%	33%	33%			33%	
(Powers 1979)	1969-1978	High-rise office buildings	254	98.8%	100%					
(Powers 1979)	1969-1978	High-rise buildings (excl. office)	1394	98.4%	100%					
(Powers 1979)	1969-1978	Low rise buildings	4061	95.8%	85%	12%	3%			
(Marryatt 1988)	1886-1986	All sprinklers	9022	99.5%	100%					
			Mean	94.7%	73%	14%	10%	15%	9%	2%
			St. dev.	4.4%	23%	10%	5%	4%	12%	N/A

Figure 2: Reason for sprinkler failure - Reprinted - Frank et al.: A review of sprinkler effectiveness studies, Fire Science reviews 2013 2:6

Greater sample sizes appear to capture higher nominal effectiveness values and it should be noted that the highest of 99.5% [5] is a direct reflection of the effectiveness of systems installed in accordance with AS 2118, where above average testing and maintenance system requirements are high by international standards. Australian evidenced data remains higher than most other international datasets for effectiveness. Although it is important to note that in a paper reviewing sprinkler effectiveness studies, the highest probability of sprinkler effectiveness is likely to be in the range of 90 - 95% [6]. This is attributed to the variation in the definition of 'sprinkler effectiveness' across key studies, and the resulting implications on the upper and lower limits of the data contained within them.

3.4 Fire ignition sources

The following fire ignition sources will be considered to analyse the impact of sprinkler protection:

1. *Fire originating in an apartment; and*
2. *Fire originating on a balcony / private open space.*

Other ignition sources relating to an external fire-source feature in proximity to the physical boundary of combustible cladding such as fires from a near-by parked vehicle is not considered in this analysis.

3.4.1 Internal fires

Internal fires will range in size. For the purposes of reviewing and considering the benefits provided by sprinkler protection to the occupants of the building, against the potential adverse impact of retaining combustible cladding on the building; an internal fire is assumed to always have the potential to grow and become a flashover fire and impacting on the combustible cladding.

For buildings with sprinkler protection installed, evidence shows that majority of fires will be controlled or even extinguished following activation of the sprinkler system, resulting in the fire not impacting on or reaching the combustible cladding. Data reported by the NFPA [7] reported that "almost all [97%] of the fires were confined to the object or room of origin" when a sprinkler system was present. This is clear evidence that sprinklers mitigate the extent and spread of fire, including the potential for a fire grow and result in a flashover event.

3.4.2 Balcony/private open space fires

Where the balcony is sprinkler protected, the sprinkler system is similarly expected to control or, in the vast majority of cases, suppress such a fire. Data for such fires and the reliability of sprinklers on balconies is not readily available. Sprinklers on balconies can however be expected to improve safety and reliably mitigate most of the risk posed by the fire on a balcony [8].

Together with the Australian Building Codes Board's (ABCB's) statement, in the same document referred to above, that "data on fire starts shows that 1 fire a year occurs on a new balcony", coupled with the lack of balcony fires reported in media generally, it is clear that balcony fires are generally "lacking in quantity", meaning that as a representation of overall fire point of origin – they represent a very low percentage. This is important to keep in mind when looking to mitigate risk associated with combustible cladding installed to/on balconies on buildings in the elevated risk category.

Based on data from Canada in the period spanning 2005 to 2015, "10% of the multi-residential building fires originated from an outside area (either the exterior balcony (including open porch or deck) or court/patio/terrace area)" [9].

3.5 Design capacity

The intent of CSV's investigation into the use and benefit of sprinklers was on the suppression of apartment fires, as these account for more than 90% of all fires recorded in this class of building. More specifically, the environment upon which sprinklers are being assessed is accepted as a lower cladding risk environment than what the community often regard as buildings with cladding risk (these being your classic high-rise towers clad from top to bottom, as opposed to the lower risk environments whereby an external fire spread is contained in maximum size). Data for these lower risk and lower potential fire spread buildings is not readily available in the Australian setting, either because these lower risk external cladding fire events have not occurred, or if they did, they were small (as anticipated) and not viewed as meritorious for journal or reporting write-ups.

Notwithstanding this, and using a large high-rise based reported fire in Victoria which occurred within the last decade, the value of sprinklers in injury and fatality reduction is given below.

In the Lacrosse fire of November 2014, witness reports and subsequent investigations generally concluded that the installed sprinkler system was effective in reducing the severity of the fire and reducing the spread of fire internally. The installed system was designed so that 4 sprinklers and 2 fire hydrants could be operated simultaneously on a given floor. However, it was noted that the sprinkler system operated well beyond the systems design capacity, with 26 sprinkler heads operating across 16 levels of the building over the duration of the building fire [10].

3.6 Sprinkler system installed on balconies

The effectiveness of sprinklers in general has been outlined above. Balconies range in geometries from generally open to mostly enclosed spaces, from shallow spaces to deep spaces. The effectiveness of a sprinkler head on a balcony would be greatly impacted by the geometry and layout of the balcony. The reliability of the sprinkler head(s) on a particular "generic" balcony is therefore difficult to ascertain, however good design principles and manufacturers details are available to guide effective installation in order to have sprinklers detect and supress/extinguish fires that may occur on a balcony.

National Construction Code regulations and registration practice knowledge in Australia further enhances the probability of effective sprinkler suppression properties.

In the following text, the shielding effect relating to sprinkler systems installed on balconies will be discussed. Where furniture and storage items might shield a fire in the early stages of development from sprinkler droplets, it is considered that discharging sprinklers installed to balconies would wet and cool potential fuel packages, as well as reducing temperatures in the vicinity of the shielded fire.

Balconies vary in their shape, form and extent from mostly wide and open to the sky, through to fairly enclosed "compartments". The operation of a sprinkler head located on a balcony will differ depending on the balcony enclosure geometry. While an open balcony will initially send the hot combustion products towards the sky, those same combustion products could build up on the balcony if the balcony is fairly enclosed. This will govern the time taken for the sprinkler head to activate. It should, however, be recognised that even a delayed activation of the sprinklers will have a positive benefit on any fire located externally. This holds particularly true for the discussion of the risk associated with combustible cladding on the buildings that are considered to have an "elevated" level of risk, due to some level of cladding connectivity between apartments.

Experiments that sought to spotlight the performance of automatic sprinkler systems and shielded fires demonstrated reduced fire severity. It highlighted a clear reduction in ceiling/upper smoke layer temperatures (for standard ceiling height compartments) and an ability to push the heat release rate from a 3MW crib fire to below 1MW without direct droplet and flame interaction [11].

It has additionally been demonstrated in enclosure fire tests that temperature maximums of approximately 200°C were experienced in the locations immediately proximal to a shielded fire

[12], with temperatures in areas directly exposed to discharging sprinkler heads kept below approximately 100°C.

It is important to note that the tests replicated enclosure conditions (ceiling height 3.6m), it would be expected that in a balcony fire scenario there will be at least some part of the balcony enclosure that is open (un-enclosed). In such a case, it would be expected that the resulting ceiling jet would be moving smoke out of the balcony enclosure, thereby reducing the general amount of smoke contained within the balcony enclosure and effectively reducing radiation from the upper smoke layer.

3.7 Summary

In summary:

- It is considered that an internally located automatic sprinkler system will in most cases either extinguish or control a fire, hence mitigating fire spread and the potential for a flashover event to occur.
- Where a fire continues to burn after sprinkler activation, the heat release rate from that fire is capped.
- Sprinklers systems are taken to be reliable 95% of the time and effective 95% of the time.
  - ✓ Data from NFPA in 2010 stated that sprinklers operate in 95% of structure fire scenarios and, when activated, control and suppress the fire in 92% of the cases.
  - ✓ A 2013 review of sprinkler system effectiveness studies found that sprinklers are effective 90-95% of fire scenarios.
  - ✓ Data from NFPA spanning 2015 to 2019 stated that sprinklers operated in 92% of the fires in which they were present and the fire was considered large enough to activate them. It further stated that they were effective at controlling the fire in 96% of the fires in which they operated. Taken together, sprinklers operated effectively in 88% of the fires large enough to trigger them.
  - ✓ The building stock in Australia that have been built with combustible cladding are newer than the general building stock in America that the data above is based upon. As the buildings are newer, the installed sprinkler system is also going to be newer than some of the legacy systems included in the above NFPA data, meaning that the reliability of the sprinkler systems should be higher than that documented from the above statistics.
  - ✓ Bafsa [13] stated in 2015 that "Given that sprinklers have been around for more than 140 years, a vast amount of knowledge and data have been accumulated on the way they work and their effectiveness and reliability. From this data, it is now widely accepted that where systems are correctly designed, installed and maintained there is a better than 99% chance of a sprinkler system controlling or actually extinguishing a fire."
- Sprinkler activation on a balcony has a strong potential to extinguish or cap a fires heat release rate. It further has the potential to become an active measure of controlling or stopping fire spread back into the building.
- Smoke from an (internal or external) fire has the potential of spreading via open windows and reach other SOUs within a building before the sprinkler system is activated. This holds true irrespective of the cladding being combustible or not. The detection of smoke in bedrooms is therefore considered an overall betterment for early local detection and alarm in the event that smoke has spread to a bedroom in for instance the SOU above where the fire has originated.
- The activation of the sprinkler system will further result in the activation of the buildings occupant warning system to alert the rest of the building occupants.

4 Statistics

4.1 Deaths and injuries to occupants

NFPA data from the US [7] records the difference between sprinkler protected and non-sprinkler protected buildings in relation to deaths per 1,000 fires. The civilian death rate per 1,000 fires in homes with sprinklers was 1.0 vs 8.1 deaths in homes without sprinklers[1].

Sprinklers also provide a betterment when it comes to injuries from fire. The betterment is not, however, as large as for deaths. The same NFPA document states that “when sprinklers were present, almost all of the fires were confined to the object or room of origin. The majority of civilian deaths and injuries resulting from fires in homes with sprinklers were caused by these fires. In home fires that lacked AES [Automatic Extinguishing System], only three-quarters of the fires were confined to the object or room of origin. Only one in five deaths and half of the injuries in home fires with no AES present resulted from such fires.”

This would appear to indicate that the injuries in particular (as well as the deaths) are a result of either the initiating event itself or first-aid firefighting attempts by individuals.

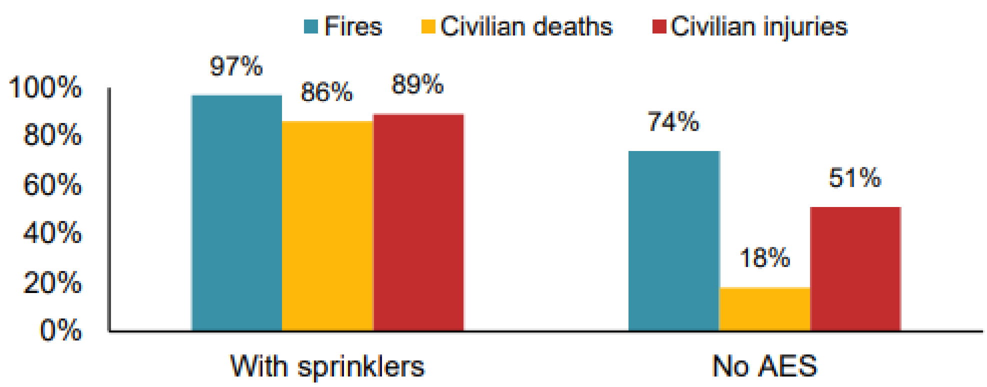

Figure 3: Percent of home fires, injuries, and causalities resulting from fires confined to object or room of origin: 2015-2019 – reprinted – US experience with sprinklers, NFPA, October 2021

AES Presence and Type	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions)	
AES present	**25,000**	**(7%)**	**24**	**(1%)**	**593**	**(5%)**	**$197**	**(3%)**
Sprinklers present	23,600	(7%)	23	(1%)	555	(5%)	$194	(3%)
Wet pipe sprinkler system	*21,000*	*(6%)*	*22*	*(1%)*	*477*	*(4%)*	*$185*	*(3%)*
Dry pipe sprinkler system	*2,100*	*(1%)*	*1*	*(0%)*	*69*	*(1%)*	*$8*	*(0%)*
Other type of sprinkler system	*500*	*(0%)*	*0*	*(0%)*	*9*	*(0%)*	*$1*	*(0%)*
Non-sprinkler AES present	1,400	(0%)	1	(0%)	38	(0%)	$3	(0%)
Partial system AES present	900	(0%)	5	(0%)	40	(0%)	$25	(0%)
AES not in fire area and did not operate	500	(0%)	0	(0%)	28	(0%)	$24	(0%)
None present	**318,500**	**(92%)**	**2,587**	**(99%)**	**10,408**	**(94%)**	**$6,907**	**(97%)**
Total	**344,900**	**(100%)**	**2,616**	**(100%)**	**11,036**	**(100%)**	**$7,153**	**(100%)**

Figure 4: Summary of AES presence and type in reported home structure fires, excluding properties under construction: 2015-2019 – reprinted – US experience with sprinklers, NFPA, October 2021

[1] We note that these values (from page 11 of the NFPA document) are somewhat more conservative than the values provided on page 14. It is not clear from the document why the values on the two pages differ. As such the more conservative value is used in this document.

4.2 Value relating to property loss

In 2012 the Fire Protection Research Foundation, in support of the NFPA, presented research on "sprinkler impact on fire injury" [14]. This research confirms that that the cost associated with a fire is reduced when a sprinkler system is installed in the property.

The analysis breaks the costs associated with the fires down into multiple components. Notably the study concluded that for the just under 350,000 fires that occurred in buildings without a sprinkler system, there would have been savings as follows:

- a 53% reduction in civilian fire injury medical cost = a saving of $0.2 billion a year;
- a 41% reduction in civilian fire injury total cost = a saving of $0.7 billion a year;
- a saving of 6 lives per 1,000 fires = a saving of $10.4 billion a year; and
- a 69% reduction in property damage = a saving of $4.8 billion a year.

A similar study was undertaken in 2017 by NFPA. That study formed, at least in part, the basis for the Australian Building Codes Board's decision to lower the building height threshold / "trigger point" for when sprinkler protection is requiring in residential apartment buildings under the deemed to satisfy provisions of the National Construction Code of Australia.

In July 2021 the Federal Emergency Management Agency (FEMA) presented values in a report titled "One- and Two-Family Residential Building Fires (2017-2019)". This report included values for property loss in such buildings as well as other residential buildings. This report gives insights into deaths and injuries per 1,000 fires and loss (cost) per fire [15].

From the US Census data we can get an estimate for the number of households in the US, based on the type of household, e.g. 1 housing unit, 2 to 4 housing units, condominium etc [16].

Measure	One- and two-family residential building fires	Confined one- and two-family residential building fires	Nonconfined one- and two-family residential building fires	Residential building fires (excluding one- and two-family)
Average Loss				
Fatalities/1,000 fires	7.9	0.0	13.2	3.3
Injuries/1,000 fires	25.3	5.5	38.4	25.7
Dollar loss/fire	$22,030	$290	$36,390	$13,190

Source: NFIRS 5.0.
Notes: 1. Average loss for fatalities and injuries is computed per 1,000 fires; average dollar loss is computed **per fire** and rounded to the nearest $10.
2. The 2017 and 2018 dollar-loss values were adjusted to 2019 dollars.

Figure 5: Loss measures for one- and two-family residential building fires (3-year average, 2017-2019), FEMA

4.3 Fire fighter injuries

The average firefighter fireground injury rate per 1,000 reported home fires was 78 percent lower when sprinklers were present than in fires with no sprinklers installed.

5 Analysis

5.1 Fire scenarios

The probability of a building fire occurring in the first place is a low probability event. The probability of a building fire that occurs and grows to the point that it spreads within an apartment and out of that apartment is even smaller.

Based on the data from the US Census Bureau and NFPA the probability of a fire occurring in any given apartment is 0.36% [17].

5.1.1 Internal fires

An internal fire is considered to be the main fire scenario for any particular building. Since the building is sprinkler protected and the sprinkler system is expected to be operating and be effective in 90-95% of all fires (where the fire doesn't self-extinguish in the very early stages, i.e. the fire continues to grows to the point that a sprinkler heads would have otherwise been expected to operate), the only risk to any sole occupancy unit (SOU) through fire spread via the cladding is the 5-10% of those fire where the sprinkler system does not operate/does not suppress the fire.

In those 5-10%, the fire could reach the combustible cladding and heat and smoke could foreseeably spread to the SOU connected via such cladding.

5.1.2 External fires

5.1.2.1 A publicly accessible area

This would generally be a fire source near the combustible cladding located at ground floor.

As the cladding is accessible, and if the cladding connects two or more apartments, then the rules of ground-based PMCR interventions should take precedence – which could likely result in the removal of cladding at/near ground level. This ignition source is not the target of the analysis in this work.

5.1.2.2 Balcony (or other non-publicly accessible area/private open space)

From 2005 to 2015, BRE Global reported on 24 fires which started on balconies. There is a trend of balcony fires increasing in frequency, with one such fire reported in 2005 and six reported in 2015. With new buildings incorporating more balconies and outdoor spaces than in the past, this could – at least partially – explain the increase in frequency. Another reason could be that balconies are being used as storage locations, due to the combination of decreasing apartment sizing and the (potential) increase in "things" each person accumulates over a lifetime [18].

5.2 Assessment of risk

The data in this section has been source predominantly from the United States. Australia is known to not have adequate nor reliable data with regards to fires. With regards to fires, the United States is in many ways similar to Australia, meaning that the data from the United States is expected to be reasonably comparable to data from Australia (if such data was available).

At the time of this report, there is scattered data from other regions such as Canada, New Zealand and England with similar figures. However, the incompleteness and/or outdated nature of those data makes them less robust for the calculation; consequently, the data from the United States was used noting a certain conservative level in the estimation when compared to these valid sources.

5.2.1 Likelihoods

5.2.1.1 Of a fire starting

NFPA reported that the average number of structure fires in the period 2016-2020 was 343,100 [19].

Of these fires, 5%, or 17,155, were classified as "Unclassified outside area" fires.

NFPA separately reported that in the period 2014-2018, the US fire department responded to an estimated average of 10,600 home structure and outdoor fires involving grills. 5,700 (53.8%) of these had a fire origin as being either "Outside or Unclassified Fires" [20].

As the likelihood of fires on balconies appears to be increasing, for the purposes of this document it is conservatively assumed that the 5% of all fires that were classified as "Unclassified outside area" fires were balcony fires.

For this report it is conservatively assumed that each of those fires would impact on the combustible cladding.

From the latest census data, there were 124,010,992 households in the United States [21].

If it is conservatively assumed that all of these households have a balcony, then the likelihood of a fire occurring on any one balcony is 0.0138% and the likelihood of a fire occurring in any given SOU is 0.2628%, over a fire year period. The reality is that the probability of a building fire is significantly lower, as not all apartments have balconies to act as a source of ignition.

5.2.1.2 Of a fire spreading

The connection between SOUs, by way of combustible cladding, is assumed to facilitate fire spread 100% of the time a fire impacts on the cladding, i.e. where the sprinkler system is assumed to not be effective.

The fire is also conservatively assumed to be able to spread up 100% of the times and down 90% of the times. Sideways fire spread has not been looked at separately, but is known to be reduced by a significant factor compared to a vertical fire as observed from real building's cladding fires and is instead very conservatively covered by the calculations for vertical spread.

The overall likelihood is then calculated by adding up all the possible fire spread scenarios, to provide the likelihood of a fire occurring in the cluster of connected SOUs.

5.2.2 Consequences

The consequence for a person in one SOU is assumed to be equal to the death rates or injury rates given earlier in this report, i.e., 1 death in every 1,000 fires for a sprinkler protected SOUs and 8.1 deaths in every 1,000 fires for non-sprinkler protected SOUs as described in section 4.

5.2.3 Benchmarks

5.2.3.1 SOU

The calculations below benchmark the individual SOU risk (the individuals within) to each of the SOUs in a sprinkler protected building which has combustible cladding connecting SOUs, against the risk to (the individual within) an SOU of a non-sprinkler protected building where there is no cladding connection to adjoining SOUs.

5.2.3.2 Cluster

It further assesses the societal SOU risk by comparing the overall risk of the cluster of SOUs that is connected by combustible cladding, against the combined risk of the equivalent number of SOUs in a non-sprinkler protected building.

5.2.3.3 Low

The first benchmarking being assessed is against what has been deemed a “Low” risk by the Victorian government.

5.2.3.4 Elevated

The second benchmarking being assessed is against what has been deemed an “Elevated” risk by the Victorian government.

5.3 Calculations

By relying on the data sets from the US, as referred to earlier in this document, the death and injury rates per 1,000 fires have been estimated for apartment buildings and further down to the SOU level. The following explanation is on death rates as the consequence. The estimation with injury rates follows the same method.

In terms of deaths per 1,000 fires (or death rate from here on), the data is discretised into two cohorts of (1) one- and two- SOUs per building and (2) apartments. The former represents detached and town houses while the latter is more relevant to the buildings that are the target of this analysis.

If $d_1$and d_2 are the death rates and $n_1$and n_2 are the number buildings/houses in cohort (1) and (2) respectively. The death rate in the residential cohort is:

$$d = \frac{\sum_{i=1}^{2} d_i n_i}{\sum_{i=1}^{2} n_i}$$

As a result, the death rate in each apartment per building is:

$$d_2 = \frac{d \sum_{i=1}^{2} n_i - d_1 n_1}{n_2}$$

With the assumption that it is not plausible for two fires to start in the same building from two *independent* ignition sources at the same time, the death rate in apartment buildings per SOU is calculated as:

$$d_2^{SOU} = \frac{d_2 n_2}{n_2^{SOU}}$$

where n_2^{SOU} is the number of households in cohort (2).

Table 1: Deaths and injuries per 1,000 fires in apartments in non-sprinklered buildings

	One-Two-SOUs (per building)	All residential	Apartment (per building)	Apartment (per SOU)
Deaths per 1,000 fires	7.90	8.122449	9.744	2.924
Injuries per 1,000 fires	25.30	32.678179	86.449	25.944
Cost per 1,000 fires	$22,030	$21,686	$19,179	-
No. of building	6.68E+07	7.60E+07	9.17E+06	-

In addition, data from research by NFPA (2012) on “Sprinkler Impact on Fire Injury” shows that sprinkler protected buildings could have a reduction of 41% in cost of injury (including medical cost, lost work time and pain and suffering). This adjustment is also reflected in the calculation.

Based on benchmarks set out above and earlier in the report the values from the calculations are presented in the table below. The values for the calculations for the elevated benchmark have been normalised and all benchmark values used are the lower value of the values in the cluster, i.e., the more conservative values. For cladding risk values, the highest value, being from the topmost SOU in a vertical cluster, have been used, i.e., the more conservative values.

If α and β are the likelihood of a fire starting inside and, on a balcony/private courtyard area of an SOU and conservatively assuming that there is otherwise no fire spread beyond the SOU of fire origin, the benchmark for Low of individual SOU risk (R_2^{SOU}) and societal SOU risk (R_2) are:

$$R_2^{SOU} = (\alpha + \beta) d_2^{SOU}$$

$$R_2 = \sum_{i=1}^{N} R_2^{SOU,i}$$

where N is the number of SOUs in the cluster.

The cladding risk of the cluster composing of N SOUs connected by combustible cladding in a sprinkler protected building is calculated as:

$$R_{2,SPRK}^{SOU,i} = (\alpha + \beta) d_{2,SPRK}^{O} + \sum_{i=1}^{N-i} (\alpha + \beta) \delta_u d_{2,SPRK}^{B} + \sum_{i+1}^{N} (\alpha + \beta) \delta_d d_{2,SPRK}^{B}$$

$$R_{2,SPRK}^{Cluster} = \sum_{i=1}^{N} R_{2,SPRK}^{SOU,i}$$

where $R_{2,SPRK}^{SOU,i}$ is the individual SOU cladding fire risk in sprinkler protected buildings of SOU i in the cluster;

$R_{2,SPRK}^{Cluster}$ is the societal SOU cladding fire risk in sprinkler protected building of the cluster;

$d_{2,SPRK}^{O}$ is the death rate which occurs in the SOU of fire origin in sprinkler protected buildings;

$d_{2,SPRK}^{B}$ is the death rate which occurs beyond the SOU of fire origin in sprinkler protected buildings;

δ_u and δ_d are the probability of cladding fire to spread upward and downward between SOUs in the cluster. It is conservatively assumed that cladding fire always spread up ($\delta_u = 1$) and highly likely to spread downward ($\delta_d = 0.9$).

Comparing with the benchmark for Low above, the relative cladding fire risk in a sprinkler protected building compared to the “Low” benchmark is:

$$I_{2,SPRK}^{individual} = \frac{\max (R_{2,SPRK}^{SOU,i})}{R_2^{SOU}} \; with \; i = \overline{1 - N}$$

$$I_{2,SPRK}^{societal} = \frac{R_{2,SPRK}^{Cluster}}{R_2}$$

The benchmark for “Elevated” of individual SOU risk ($R_{2,E}^{SOU}$) and societal SOU risk ($R_{2,E}^{Cluster}$) is calculated as follows:

$$R_{2,E}^{SOU} = (\alpha + \beta) d_2^{SOU} + (\alpha + \beta)\delta_u d_2^{SOU}$$

$$R_{2,E}^{Cluster} = \sum_{i=1}^{N} R_{2,E}^{SOU,i}$$

noting that the benchmark of individual SOU risk takes the risk of the upper SOU in the cluster as the more conservative value and N is two for the benchmark calculation.

The relative cladding fire (RCF) risk in a sprinkler protected building compared to the “Elevated” benchmark is:

$$I_{2,SPRK,E}^{individual} = \frac{\max\left(R_{2,SPRK}^{SOU,i}\right)}{R_{2,E}^{SOU}}$$

$$I_{2,SPRK,E}^{societal} = \frac{R_{2,SPRK}^{Cluster}}{R_{2,E}^{Cluster}}$$

Table 2: Relative cladding fire risk in sprinkler protected buildings compared to “low” and “elevated” benchmark

	Compared to “Low” benchmark		Compared to “Elevated” benchmark	
	$I_{2,SPRK}^{individual}$	$I_{2,SPRK}^{societal}$	$I_{2,SPRK,E}^{individual}$	$I_{2,SPRK,E}^{societal}$
	IF-SCAN = 3		IF-SCAN = 36	
Deaths	39.9%	39.3%	87.0%	85.6%
Injuries	55.9%	55.4%	98.3%	96.9%
Cost	-	68.2%		
	IF-SCAN = 4		IF-SCAN = 42	
Deaths	43.9%	43.0%	99.2%	97.4%
Injuries	60.2%	59.2%	111.0%	109.4%
Cost	-	77.6%		
	IF-SCAN = 6			
Deaths	52.1%	51.1%		
Injuries	68.7%	67.6%		
Cost	-	96.5%		
	IF-SCAN = 13			
Deaths	80.5%	78.1%		
Injuries	98.5%	96.0%		
	IF-SCAN = 17			
Deaths	96.8%	93.5%		
Injuries	115.6%	112.2%		

Table 2 shows the RCF risk of sprinkler protected buildings compared to “Low” and “Elevated” benchmarks. In general, RCF risk in terms of injuries is always higher than that of deaths.

Considering the injuries – RCF risk in the comparison to the “Low” benchmark, an IF-SCAN of 4 will obtain a RCF risk of 60% while IF-SCAN of 6 will result in a RCF risk of 70%. The highest IF-SCAN resulting in a RCF risk of less than 100% is 13 and 17 corresponding to injuries and deaths rate respectively.

When comparing to the “Elevated” benchmark, the RCF risk of lower than 100% can be obtained with the highest IF-SCAN of 36 (corresponding to injuries rate) and IF-SCAN of 42 (corresponding to deaths rate).

The loss (cost) per fire was derived for both sprinkler protected and non-sprinkler protected buildings. Relying on the above-mentioned datasets and assumptions, it was found that an IF-SCAN value of 6 results in an RCF of 96.5%.

This takes into consideration the likelihood of a fire starting either inside or outside an SOU, the reliability of the sprinkler system, the fire damage to the building (external damage due to combustible cladding) and the fire damage when such external fire spreads to the other SOUs in the cluster. The RCF is compared against the same building without the cladding and without sprinklers.

6 Discussion

6.1 Smoke alarms detectors and Occupant warning systems

Sprinkler activation should always be coupled with a general fire alarm in these buildings, in order to notify occupants as early as possible to a fire event.

Smoke from any fire in a building could potentially spread to a bedroom in an adjoining SOU before the sprinkler system is activated. This is a potential irrespective of the cladding on the building being combustible or not. The inclusion of smoke detection in bedrooms therefore further assists in mitigating risk posed by smoke from any fire in the building, as it creates detection in a space that has potentially sleeping occupants and can alert them through a local alarm notification, prior to a building wide alarm sounding.

6.2 Cladding fire risk from other external ignition sources

As stated in section 5, the analysis considers the cladding fire risk where fire is assumed to start from an SOU (either indoor or outdoor, i.e., balconies and private courtyard). Other external ignition source such as the fire from a parked vehicle in the proximity which could ignite cladding was not expressly dealt with in this document. An external fire which could ignite combustible cladding and spread fire to a certain cladding cluster or leading to the compromise of a single exit/evacuation pathway of occupants should be dealt with on an “elimination” basis. As a result, the residual cladding fire risk remains with the ignition sources considered in the analysis.

6.3 Assessing the above the results

The values for the expected number of deaths per 1,000 fires in the different buildings show a clear case for the betterment to the life safety of people in the building when there is a fire (of any origin) in the building and a sprinkler system is installed. In terms of the death rate, we can see that up to 17 SOUs (sprinkler protected) connected equate to the same level of risk as a single SOU where there is no combustible cladding and no sprinkler system installed. Up to 42 SOUs (sprinkler protected) connected have the same level of risk compared to the “Elevated” benchmark.

In terms of injuries, for up to 13 SOUs (sprinkler protected), the cladding fire risk is calculated to be reasonably similar to the “Low” benchmark, while the RCF risk reaches 70% at an IF-SCAN of 6. Up to an IF-SCAN cluster of 36 (sprinkler protected) will result in a RCF risk of equal to or less than the “Elevated” benchmark.

For property damage, up to, and including, 6 SOUs connected result in a calculated risk just below that of the “Low” benchmark.

It is noted that the figures above are calculated values of relative risk based on the likelihood of considered fire sources and consequences relating to human safety (deaths and injuries). The final categorisation for sprinkler protected buildings should be considered in conjunction with other parameters such as (and not limited to) building height and firefighting capabilities for a certain building. The data also uses reasonably comparable database from the US which may also lead to some variation for Australia.

7 References

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8 Appendices

Appendix A – PMCR document set and flow