Peer-reviewed article

Safety awareness of firefighters and their perception of fire risks in cladding fires

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ABSTRACT

Owing to the extensive use of polymers in building products, there is the urgent need to resolve the present fire risks of highly combustible cladding products. Apart from understanding the risks associated with cladding materials on buildings, it is also essential to evaluate the underlying risks of existing non-compliant materials on buildings for residents, owners, and the public, and for firefighters during the management of such fire events. In this article, a fire risk perception survey was constructed by a collaborative effort from Fire and Rescue New South Wales (FRNSW) and University of New South Wales. The survey can be subdivided into four major parts, i) demographics, ii) risk awareness and identification associated with cladding material, iii) the firefighter's own perceived risk associated with cladding fires and iv) risk mitigating behaviours. The majority of the questions are designed with five distinctive levels (i.e. ranging from rare to almost certain, or negligible to very high), and it will be distributed to firefighters from major states and rural fire agencies around Australia. The results will formulate a large and comprehensive database to increase our understanding of the firefighter’s risk perception associated with combustible cladding materials.

Introduction

Existing cladding materials such as polyethylene (PE) sandwiched between steel panels, wood-plastic composites and high-performance concrete with polymeric blends have been identified as the root cause in a number of severe fire incidents. These incidents include the Dubai skyscraper fires in 2015 and 2016 (Bannister 2015), Lacrosse Tower fire in Melbourne 2016 and the London Grenfell Tower fire in 2017 (Pasha-Robinson 2018). Furthermore, toxic emission from the pyrolysis of polymers, especially asphyxiated gases such as CO and HCN are responsible for the majority of deaths and injuries in building fires (Morikawa et al. 1993). Recently reported building cladding fires in Australia as well as in other countries have certainly created a heightened awareness by the public and have propelled governmental authorities and commercial identities to act on the risks associated with the non-compliance of such structures that have erected in the building and construction landscape (Senate 2017, 'The Grenfell Tower Inquiry' 2018, Czoch and Shukla 2018). With the constant increase in population density and compactness of building occupants on both the work and residential environment in major cities in Australia (especially Sydney and Melbourne), it is paramount to resolve the present fire risks of highly combustible building products.

Composite sandwich panels (cladding) are commonly found as surface finishes in building façade systems or Exterior Insulation Finishing Systems (EIFS) and External Thermal Insulation Composite Systems (ETICS). A diagram of a typical exterior façade system is shown in Figure 1. These systems are designed to be cost-effective solutions for thermal insulation, weather resistance and aesthetic external wall finishes. Composite sandwich panel may be included in the initial building design or added at later stages as part of refurbishment or maintenance during the life of building property.

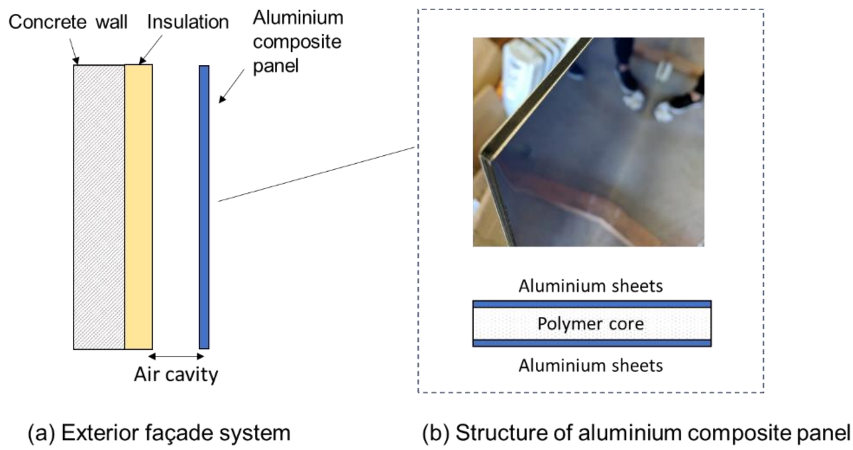


Figure 1: Diagram of (a) components of an exterior façade system and (b) the structure of the aluminium composite panel.

Aluminium composite cladding panels (ACP) consist of two thin metal sheets bonded to a central polymer insulating core. The polymer cores are often highly flammable materials such as polyethylene (PE), polyisocyanurate (PIR) or polyurethane (PUR). When ignited, the melting and dripping effect are often found to promote the fire spread vertically across the levels of the buildings, which significantly limits the amount of time for egress process, and difficulties for firefighters to access into the building to fight the fire internally or rescue trapped occupants. Based on evidence from past cladding fire incidents, the fire usually develops into an uncontrollable blaze within 10-15minutes. In addition to the flammability of cladding panels, many other factors influence the fire hazards of exterior façade systems (Bonner and Rein 2018). These include the width of the cavity between the insulation and the external panels, the types of insulation material, the installation of fire barriers in between levels, and the structural weaknesses of joints and connection between individual panels that deteriorate with high temperature (Chen et al. 2019). Fire spreading into the air cavities can cause the flame length to extend significantly to seek oxygen for combustion (Babrauskas 2018, Kim et al. 1974). There are three mechanisms which enhance the flammability in a cavity compared to a normal surface: i) increase radiative heat transfer because of the cavity, ii) increase upward flame spread from the chimney effect and iii) decrease in convective cooling from external air causing an extension of the flame height inside the cavity (Chen et al. 2019). This mechanism enables the fire to spread rapidly and hidden within the cladding system, which can be very dangerous for firefighters as hidden fires can lead to a buildup of asphyxiant gases within the panel and sudden flashovers. Furthermore, exterior façade fires also pose a significant threat of breaching compartmentation. This causes immense difficulty for firefighting operations because the most common fire strategy for high-rise buildings involves confining the fire to its floor of origin for an extended period after its initiation (Colwell and Martin 2013).

Apart from understanding the risks associated with non-compliant materials on buildings, it is also essential to evaluate the underlying risks of existing non-compliant materials on buildings for residents, owners, and the public, and for firefighters during the management of such fire events. Risk perception can be attributed to many factors including organisation factors (i.e. staffing levels; employer response of breaching the standard operating procedures) and individual factors (i.e. personalities, behavioural, attitudinal and situational biases). Risk tolerance or acceptable risks are often determined by the incident commander for emergency response personnel. The levels of risk tolerance could also be highly dependable on training, environment and education background of each firefighter. Since firefighters are generally more experienced in fire situations, they may not perceive risks the same way an ordinary person. More often, firefighters are at times oblivious to the potential fire hazards they may encounter. Therefore, it is important to construct an effective method to effectively determine the fire fighter's confidence level in various fire situations and addressing the risks that they are experiencing. Despite these concerns, there are few studies on how firefighters process and manage risks associated with combustible cladding materials (Anderson et al. 2017). In this study, qualitative research was conducted to provide a deeper understanding of the attitudes, beliefs and perception of firefighters toward fire risks associated with combustible cladding materials. The data was collected by an online survey constructed and distributed by a collaborative effort from The University of New South Wales and Fire and Rescue New South Wales.

Methodology

An online survey was performed to investigate the fire risk perception of firefighters associated with combustible cladding material. The survey was conducted on March 20 - May 20, 2019. It was completed by a total of 439 participants consisting of firefighters from major states and rural fire agencies around Australia. This research was approved by the UNSW Human Research Ethics Advisory Panel (approval number HC180884).

Participants

The survey was completed by a total of 439 participants which includes 287 (66.90%) from Fire and Rescue New South Wales (FRNSW) and 78 (18.18%) from Queensland Fire and Emergency Services (QFES) and 64 (14.92%) from other Fire Services in Australia. A full distribution of all the participating fire agencies is shown in Figure 2.

In terms of experience, 331 participants (75.40%) had over 10 years of firefighting experience, 49 participants (11.16%) between 5 to 10 years and 45 participants (10.25%) with less than 5 years of experience. Additional demographic questions regarding the participant's rank and zone were given to FRNSW participants. There is a good distribution of different ranking officers and zone locations. For example, among the participants, there were different ranking officers from FRNSW ranging from Firefighters to Deputy Captains or above and from all the regions in NSW. The majority of the participants were from Inner Sydney (Metropolitan East) which accounted for approximately 35.18% of all responses from FRNSW. A summary of the demographics of all the survey participants is shown in Table 1 & 2.

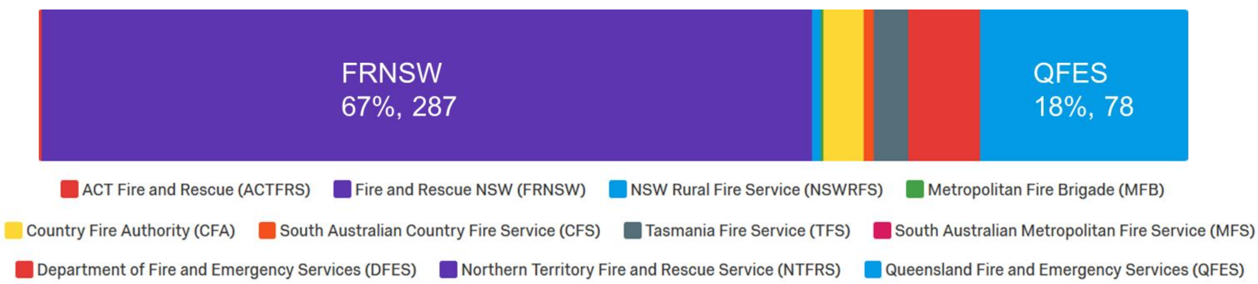


Figure 2: Distribution of the different fire service agencies in the survey participants.

Table 1: Summary of all the survey participants in terms of fire service agency and experience

Fire Services	%	Count	Experience	%	Count
Fire and Rescue NSW (FRNSW)	66.90%	287	Over 10 years	75.40%	331
Queensland Fire and Emergency Services (QFES)	18.18%	78	5 to 10 years	11.16%	49
Department of Fire and Emergency Services (DFES)	6.29%	27	Less than five years	10.25%	45
Country Fire Authority (CFA)	3.50%	15	Not a firefighter	3.19%	14
Tasmania Fire Service (TFS)	3.03%	13			
South Australian Country Fire Service (CFS)	0.93%	4			
NSW Rural Fire Service (NSWRFS)	0.70%	3			
Metropolitan Fire Brigade (MFB)	0.23%	1			
ACT Fire and Rescue (ACTFRS)	0.23%	1			

Table 2: Summary of the participants from Fire and Rescue New South Wales

Rank	%	Count	Zone / Response Area	%	Count
Recruit firefighter	0.35%	1	Metropolitan East	35.18%	95
Firefighter to Leading Firefighter	41.61%	119	Metropolitan South	11.11%	30
Station Officer or above	32.52%	93	Metropolitan North	12.96%	35
Retained firefighter	15.38%	44	Metropolitan West	18.52%	50
Deputy Captain or above	8.04%	23	Regional North	7.77%	21
Other - Please specify	2.10%	6	Regional West	5.55%	15
			Regional South	8.88%	24

Table 3: List for critical factors associated with combustible cladding fires.

Critical factors associated with combustible cladding fires
Rapid vertical and horizontal fire spread
Fire spread to surrounding structures due to falling molten/burning debris
Internal fire extension on multiple levels
Overrun sprinkler and hydrant systems
Multiple floor evacuations/rescue
Difficult evacuation of immobile occupants
Evacuation and warning system failure or unavailability
Obstructions causing difficult access for aerial appliances
Toxic smoke affecting occupants and/or bystanders
Structural collapse

Questionnaire Design

An 18-item questionnaire was constructed to investigate the risk perception associated with highly combustible cladding materials. The questionnaire was reviewed by FRNSW Fire Investigation and Research Unit (FIRU), as well as the UNSW ethical team. It was approved by the UNSW Human Research Ethics Advisory Panel (approval number HC180884). The questions can be subdivided into four major parts, i) demographic questions such as the participant's fire agency, experience and rank (Q1-3), ii) Risk awareness and identification associated with cladding material (Q4-Q9), iii) the firefighter's own perceived risk associated with cladding fires (Q10-Q14), and finally, iv) Risk mitigating behaviours (Q15-Q17).

Questions 4-9 were designed to explore risk awareness and identification of combustible cladding. The participants were asked to identify from the buildings at risks of combustible cladding from 12 images of building structures. Then they were asked to rate the likelihood of occurrence for a list of critical factors widely associated with combustible cladding (see Table 3) and the consequences of encountering these factors using the 5-point Likert scale.

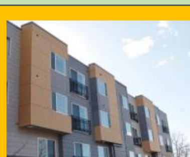
Questions 10-14 explore the firefighter's own perceived risks regarding cladding material and ask questions such as the likelihood of them facing cladding fires, the number of at-risk buildings in their zone and what are their most significant concerns and priorities when faced with such an incident. The last set of questions from Q15-Q17 deals with risk mitigation behaviours and the preparedness of the firefighter when attending fires involving cladding. The participants were asked if they have conducted any pre-incident planning (PIP) or Home Fire Safety Checklist (HFSC) for cladding buildings in their area, or any community engagement educational programs to the community. The questionnaire was first distributed in fire stations in the NSW state by FRNSW and was later extended to other fire agencies in Australia. The results will formulate a broad and comprehensive database to increase our understanding of the firefighter’s risk perception.

Results

Risk Awareness and Identification

The participants were asked to identify from the buildings at risks of combustible cladding from 12 images of building structures of which 6 have aluminium composite panel (ACP) installed. Table 4 shows a list of all the images and the number of times the images have been selected by the participants as having ACP. The results showed an almost equal distribution among all the images. In terms of correctly identifying buildings at risk of combustible cladding, 178 (53.78%) participants had the correct 6 images in their answers, which includes 92 (27.79%) responses that have selected all 12 images. Only 3 (0.09%) participants correctly identified all 6 images without any additional selection in their answer. The average accuracy rate (determined by dividing the number of correct images by the number of selected images) is approximately 0.5869 or 58.6% which is slightly higher than random guess (50%). Distribution of the accuracy rate for all the participants is shown in Figure 3. The results suggest that the majority of firefighters have difficulty correctly identifying combustible cladding. Based on the raw selection counts for each image, the participants are slightly more bias towards selecting images with reflective, smooth surface finish, a characteristic often associated with aluminium cladding. Nevertheless, cladding panels can also include powdered surface coatings or wood grain effects depending on architectural design. The results were also aligned with most of the question feedback from the participants which highlighted that any cladding materials in a façade fire are treated as highly flammable unless advised otherwise.

Table 4: List of building images with combustible cladding material. Images with combustible cladding are highlighted in orange and without combustible cladding are highlighted in green.

Image	% (count)	Image	%	Image	% (count)
1  *	8.94% (304)	5 	5.68% (193)	9 	6.12% (208)
2  *	9.62% (327)	6 	6.30% (214)	10 	8.88% (302)
3 	7.09% (241)	7  *	9.86% (335)	11  *	9.62% (327)
4  *	9.77% (332)	8  *	9.80% (333)	12 	8.33% (283)

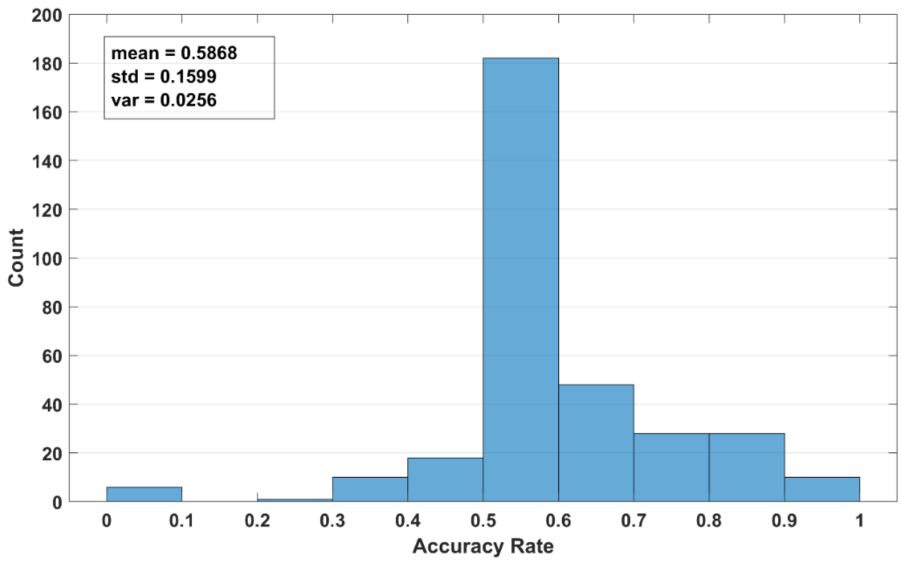


Figure 3: Histogram of the accuracy rate of identifying combustible cladding

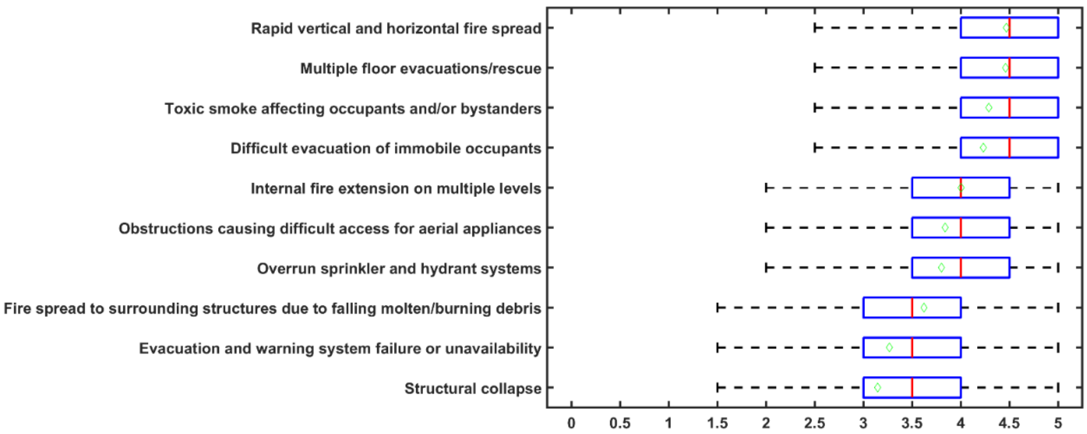


Figure 4: Risk rating for critical factors associated with combustible cladding materials. In the box plots, the boundary of the box indicates the 25th and 75th percentile, the red line within the box marks the median, and the whiskers indicate the 95th and 5th percentiles. The green circle indicate the mean.

Risk Perception of combustible cladding material

As mentioned previously, the participants were asked to rate the likelihood of occurrence and the consequence (severity) for a list of 10 critical factors for a combustible cladding fire in a multi-level building (refer to Table 3). The ratings were given on a 5-point Likert scale (5: Very High, 4: High, 3: Moderate, 2: Minor, 1: Negligible). The responses from both questions were aggregated to calculate an average risk score for each of the factors. The resulting distribution of risk scores was used to rank the list of critical factors in the order of what firefighters perceive as being the most risky. Figure 4 illustrates a box plot of all the critical factors rearranged in the order of the highest mean risk score. As can be seen in figure 4, there are three significant groups of critical factors ranked based on the firefighter's perception. The most important factors to consider in a cladding fire for firefighters include i) rapid vertical and horizontal fire spread, ii) multiple floor evacuations/rescue, iii) toxic smoke affecting occupants and/or bystanders and iv) difficult evacuation of immobile occupants. The commonality across the top ranking factors are occupant evacuation and safety. Internal fire extension on multiple levels, overrun sprinkler and hydrant systems and evacuations and warning system failure are all rated lower than the first group even though these have a significant impact on occupant evacuation and have found to occur in past cladding fire incidents. For instance, in the tragic Grenfell fire, most of the occupants were reportedly trapped in between levels due to fire extensions on multiple levels.

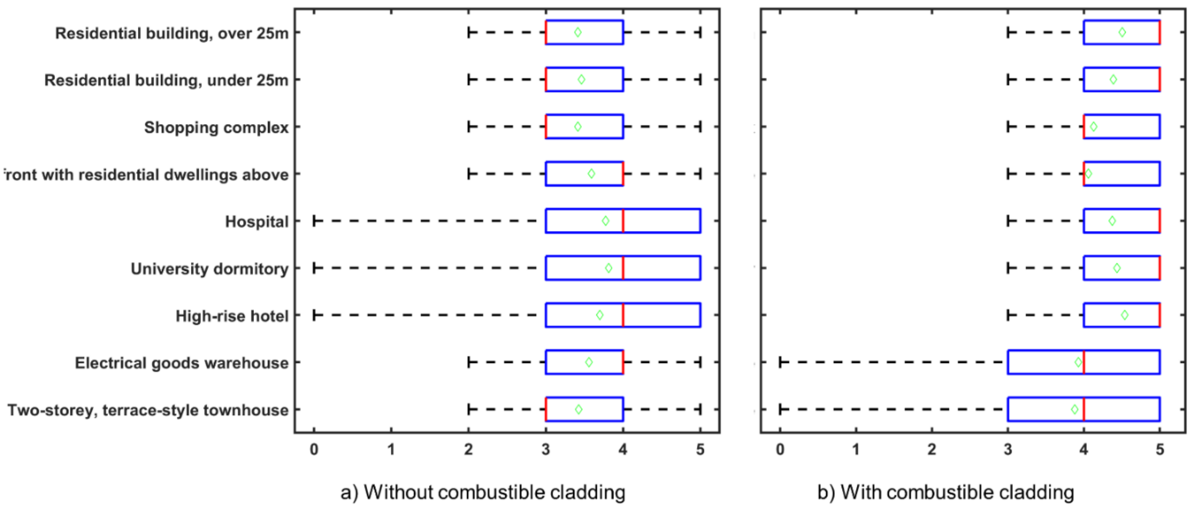


Figure 5: Risk rating for different building types in structural fire with and without involving combustible cladding. In the box plots, the boundary of the box indicates the 25th and 75th percentile, the red line within the box marks the median, and the whiskers indicate the 95th and 5th percentiles. The green circle indicate the mean.

The participants were asked to rate the consequence(severity) of fires with and without involving combustible cladding for different building types. The results showed that for normal building fires, there is no strong significance to suggest certain building types are more at risk. Based on the mean of the responses, hospital, high-rise hotel and university dormitory were perceived to be more at risk than the rest of the building types. When comparing fire with and without involving combustible cladding, there is a significant increase in risk rating across all building category when the structural fire involves combustible cladding. Particularly, the increase is most significant for Residential Buildings (over and under 25m) and High-rise hotels. This can be better highlighted in Table 5, which shows the mean severity value for fires in different building types with and without cladding and calculated the difference. The mean risk rating for residential buildings over and under 25m increase from approximately 3.4157 and 3.4607 to 4.5060 and 4.3886 respectively, which are higher than all other building types. The results suggest that the building type that firefighters perceived as most at risk from combustible cladding are residential buildings and high-rise hotels.

Table 5: Mean severity rating for fire incidents for different building types with and without combustible cladding.

Building Type	Risk Rating without cladding (mean)	Risk Rating with cladding (mean)	difference	std
Residential building, over 25m	3.4157	4.5060	1.0904	0.95
Residential building, under 25m	3.4608	4.3886	0.9277	0.87
Shopping complex	3.4157	4.1295	0.7139	0.88
Single shop front with residential dwellings above	3.5904	4.0602	0.4699	0.88
Hospital	3.7741	4.3735	0.5994	1.08
University dormitory	3.8133	4.4337	0.6205	0.93
High-rise hotel	3.6988	4.5392	0.8404	0.98
Electrical goods warehouse	3.5602	3.9277	0.3675	0.88
Two-storey, terrace-style townhouse	3.4247	3.8795	0.4548	0.87

The participants were asked to rank their priorities in a structural fire, with 1 being your highest priority and 6 being your lowest priority. The results showed that the top priority for firefighters when facing a fire incident is the safety of his/her crew and the firefighter's own safety. This is in line with current Standard Operational Guideline (SOG) which emphasise firefighter safety as the foremost consideration. It is followed by the safety of children and disabled and adult occupants. Note that there is almost no variation in these two categories, which suggests an overwhelming majority of participants ranked the safety of children and disabled and adult occupants third and fourth, respectively. At the lowest priority are protecting property and surroundings from further destructions as a result of the fire and safety of pets and wildlife.

Risk Mitigation Behaviour

In addition to the risk perception and identification questions, a series of questions were also asked to understand what firefighters think about their overall readiness in attending fires involving combustible cladding. From the 439 participants, only 11.57% of the participants that have attended a fire that involved non-compliant/combustible cladding products. 68.55% have not, and 19.88% answered that they don't know. Nevertheless, 85% of participants think they will likely attend a fire involving combustible cladding in the future, with 48.66% of participants think they will counter within the next 5 years. In terms of the level of preparedness in attending incidents involving combustible cladding, figure 7 shows the results on how the participants rated their level of preparedness in attending an incident involving highly combustible cladding. 39.40% of participants rated their preparedness for combustible cladding as less than other types of fire while 57% rated their preparedness as the same for all other fires. Only 3.64% said they were more prepared for cladding fires.

The participants were asked to select which options would help them feel more prepared for fire incidents involving combustible cladding. There is an equal distribution between the options that were given in the question. This suggests that all the approaches are equally important towards improving readiness for cladding fire incidents. There is a significant amount of comments to this question that have specifically highlighted the need for better aerial equipment and tactics. As the fire often extends beyond the reach of firefighters when they arrive. Another issue that has been highlighted among the comments were the current identification procedure relies heavily on outside parties or building managers to report the issue to fire agencies. Once filed, assessors are sent to verify the claim.

Figure 6: Priority of firefighters in a structural fire. In the box plots, the boundary of the box indicates the 25th and 75th percentile, the red line within the box marks the median, and the whiskers indicate the 95th and 5th percentiles. The green circle indicate the mean.

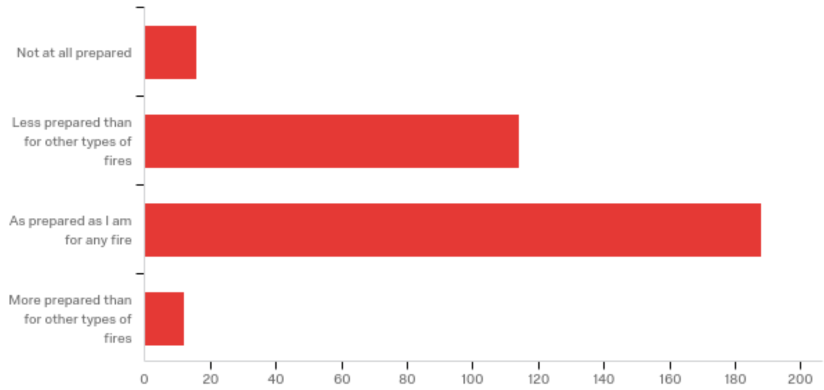


Figure 7: Responses to the question: How would you rate your level of preparedness in attending an incident involving highly combustible cladding?

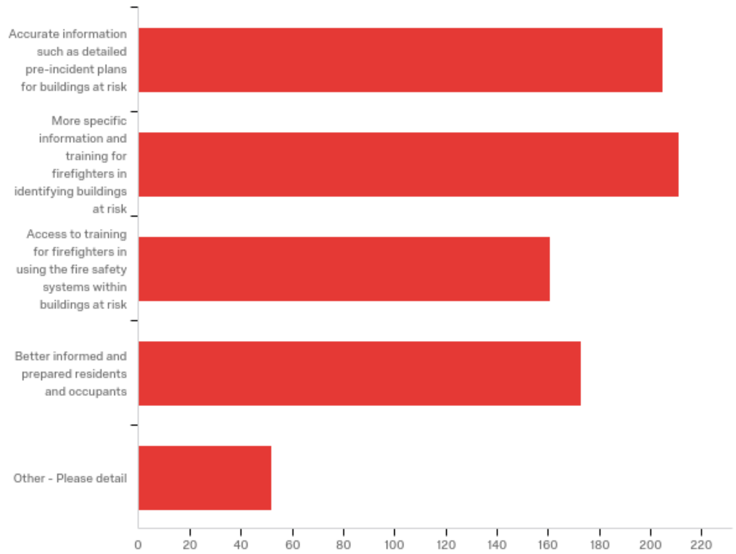


Figure 8: Responses to the question: What do you think would help to make you feel more prepared for an incident involving combustible cladding?

The process has left many unverified buildings with "potential" combustible cladding. The results emphases the importance of accurate information and planning towards effective firefighting operations as it ensures that the most optimal equipment and task crew are deployed. As such, accurate information such as PIP is a top priority to improved readiness and thus reduce the risks of fire incidents in buildings with combustible cladding materials.

Conclusion

Lightweight polymeric materials and composite panels have gained a rapid increase in utilisation due to their low-cost, easy to shape, excellent insulation characteristics and aesthetically attractive. Today, aluminium composite panels are being used in commercial, residential, hospital, and high-profile buildings. However, the polymer materials within the panels such as expanded polystyrene (EPS) and low-density polyethylene (LDPE) are highly flammable and now poses major fire risks impacting people and the economy. Furthermore, it has also become a risk for firefighters and first responders during the operations of such fire events.

In this article, an online survey was formulated to evaluate firefighter' perception and willingness for fire risks associated with combustible cladding material. The aim is to develop a database for the evaluation of risk perception and risk-taking behaviours in firefighters as pertaining to cladding-related fire events. The survey was successfully conducted during the period from March 20 to May 20, 2019 and was completed by a total of 439 firefighters from major state and rural fire agencies around Australia. Based on the results, it was found that that majority of firefighters cannot reliably identify combustible cladding (ACP)s and when attending such event, it is critical to have correct intelligence from pre-incident planning (PIP) reports. Improved PIP will also lead to more effective deployment upon dispatch and ensures appropriate gear is deployed. Furthermore, access to better aerial equipment has been repeatedly brought up in the survey as essential for tackling cladding fires.

Regarding the level of preparedness in attending incidents involving combustible cladding, firefighters in Australia currently have very limited actual experience with combustible cladding fires with only 11.57% of the participants having had attended a fire that involved non-compliant/combustible cladding products. Furthermore, 39.40% of participants rated their preparedness for combustible cladding as less than other types of fire. The results suggest that more specific information and tactical training is still needed the improve the current system of approaches for handling fire incidents in buildings with combustible cladding materials.

Acknowledgements

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