A Word from the Editor

All,

The last issue of the year!

This year has been filled with emotions of all types; kind of a roller coaster ride and unfortunately we still have a bit left of that ride. For most of us, it has been a difficult year where we have had to adapt and reinvent ourselves to a certain degree. This applies very much to this magazine and before anything else I would like to show my gratitude to the SFPE staff, the editorial board, and all you readers out there. Without all of you, we would not have the success we have; we are sharing knowledge in its true sense.

I will keep it short for this final Editors column of the year and I just wanted to say that we have some good articles in this issue, we have a few “presents” for you, I am sure they will be read a few times and used in real-life projects. So please dig in and start reading.

I would also like to promote the upcoming SFPE Europe Virtual Conference that is being planned for March, just a few months away now. I can assure you that there are a number of interesting presentations to be held. I really hope to see you all virtually for the event.

If there are readers out there that feel that they have an important subject that they would like to share with the industry do not hesitate to contact us, we can make that happen.

As always, a great thanks to the people who have put in a lot of time and effort to make this issue a reality.

The next issue will come in March.

Finally, I would like to wish all our readers a Happy Holiday & Happy New Year!

Yours sincerely,

Jimmy Jönsson, Managing Editor
A Message from the SFPE Europe Council Chair

Dear SFPE Europe members,

In case you have not heard it yet: SFPE Europe has officially been established! As an official part of becoming a legal entity in Belgium, putting in effect a Royal Decree, SFPE Europe is an international non-profit organization, run by four Board members: Nicole Boston, Armelle Müller, David Grossmann and the undersigned. Many, many thanks for all that have contributed to this – it is a major step forward to develop and contribute to the fire engineering profession in Europe. Inspired by Swiss clockwork precision and efficiency, we would like to try and develop SFPE Europe accordingly – the how and what will be explained in more detail in the coming months. The rough outlines you may have seen already in the webinars we have provided last month. Bottom line: if we really want something, it takes a bit of endurance, but eventually success is there to celebrate!

When writing this column, we have had the first touch of nice frost. That normally invokes some pondering about the coming winter and the holiday season ... Such pondering is of course influenced, apart from the above, by the influence on the vaccines. The pondering turns into wondering ... Bottom line: when we really throw a lot of effort into resolving a challenge (to find a vaccine), we can achieve it in a record-breaking period (a couple of months) and with mind-blowing effectiveness (>90%).

So, 2021 will be the year to experience the new normal, with a vaccine ... and with SFPE Europe .... Hopefully, this will generate new options for meeting face to face again. For a networking entity and essentially existing for you, our members, we do appreciate the added value brought about by face-to-face meetings. But if anything, we have learned it is that video-calls and virtual conferences deserve a permanent place in our new normal: a more frequent and efficient exchange of thoughts and information is certainly possible and desirable. Traveling and its consequences on the environment will be positively impacted.

Together we can achieve great things, setting aside our differences, and focusing on a common objective makes the world a better and (fire) a safer place to live in. As fire engineers, we have a responsibility to contribute to this. Now let us prove that we bear the responsibility, and with pride.
A healthy and prosperous 2021 for you and your beloved ones – hope to see and meet you soon,

Kees Both SFPE Europe Council Chair 2019-2020

PS: I am happy to hand over the pen to David Grossmann, who will be the next SFPE Europe Council chair.
SMART Sprinkler for Highly Challenging Fires

By: Yibing Xin, FM Global, Research Division, Norwood, MA 02062, USA

Introduction

In the world of modern distribution, larger warehouse structures now combine high vertical storage and enormous enclosed volumes for the sake of efficiency-lifting and retrieval technologies, making it possible to stack products higher than ever. To minimize fire risks, some businesses have installed in-rack automatic sprinklers (IRAS): sprinkler systems within the rack configurations often used to store products on pallets or in containers. Compared to ceiling-only protection, the IRAS are often more expensive and inconvenient for warehouse operation. Moreover, in certain situations such as portable racks and forest product storage, combustible commodities could be stacked up to 80 ft (24 m) high, but there is no infrastructure to support the IRAS. In those storage scenarios, traditional ceiling-only sprinklers encounter tremendous challenges. Why? Traditional sprinklers descended from innovations of the 19th century rely on a sensible element within the sprinkler to activate water flow. If a fire begins at or near the base of a roll paper stack, the temperature at the ceiling may not be hot enough to activate until the fire has grown substantially and perhaps spread far beyond its origin. When activated, sprinklers farther away from the fire origin sometimes activate earlier than those closer (i.e. sprinkler skipping). Sprinkler skipping, caused by water droplet impingement, is detrimental to the effectiveness of protection. For the activated sprinklers, downward water transport is often impeded by a large or rapidly growing fire. However, efforts to make traditional sprinklers more sensitive, such as lower temperature rating, could backfire due to erroneous activation in regions with very warm climates.
Highly Challenging Fires

Highly Challenging Fires (HCFs) are fire hazards that cannot be protected under existing protection recommendations. The combination of high storage and potential fire spread is a typical example of HCFs that demand protection beyond the guidelines for use of traditional sprinklers. FM Global Research explored the notion that the greatest strength of traditional sprinklers is their essential problem: the shared detection and actuation mechanisms. These mechanisms have yielded remarkably reliable and predictable responses to fire, but have proven insufficient when fires are far from the sprinkler. Moreover, distance increases the possibility that sprinkler activation will come too late to contain the fire spread. Given the technologies now available, the option of activating sprinklers on the basis of sensors located at a distance, such as in a deluge system, where large groups of sprinklers are activated simultaneously, could be expanded to an intelligent protection system with limited and controlled sprinkler operation. This motivated the development of the SMART sprinkler protection system that uses Simultaneous Monitoring, Assessment and Response Technology (SMART).

SMART Sprinkler Development

Although the SMART sprinkler may have begun as a concept, it soon took physical form in an effort to make a practical determination of how best to identify a hazard and respond effectively (Xin, Burchesky, de Vries, Magistrale, Zhou & D’Aniello, 2017) [1]. The system design starts with the objective of detecting, locating and suppressing a fire as early and as locally as possible. Avoiding the damage that can come with unnecessary sprinkler activation was also a concern, and an important driver in requiring two types of detection signals. Laboratory
experiments were conducted with a range of fire sizes and fire locations being used to test the
detection capabilities and evaluate the wireless communication employed in the prototype
system. This was followed by efforts to distinguish optimal sprinkler spacing and activation
scenarios. For both detection accuracy and speed of response, the experiments showed the
value of using multi-detector technology, specifically for rising temperature and the presence of
smoke. Having two types of sensor reduces the likelihood of a false trigger and can help
pinpoint a fire more a than a single sensor.

Speed of actuation was a key design goal. In many applications a ceiling-only approach using
traditional sprinklers is inadequate due to its slow response relative to fire propagation and
sprinkler skipping. The aim of SMART sprinkler technology is to connect rapid detection,
intelligent fire location and suppression to create more cost-effective solutions for users. Rapid
detection achieves early suppression when the fire is still small, which is the key either to
reducing water demand or suppressing more challenging fires. In principle, detection is limited
only by the sensor’s capabilities. The controlled and coordinated activation of a group of
sprinklers around the fire origin allows for proactive response to get ahead of fire spread via
pre-wetting, instead of the reactive response by traditional sprinklers. For example, in a fire test
of 7-tier (35 ft or 11 m) rack storage of cartoned commodities, the traditional sprinkler would
not activate until flames were approximately 40 ft (12 m) above the floor. The SMART system
activated when the flames were only 10 ft (3 m) high, a 75% reduction (Xin, Burchesky, de

By separating fire detection from sprinkler activation, the sprinklers can not only be activated
earlier but also in a more intelligent manner, which is essential for highly challenging fire

Figure 2. Comparison of fire sizes upon SMART and traditional sprinkler activation.
scenarios. One example is that building structures such as purlins and girders can channel ceiling flow to create highly distorted sprinkler activation patterns (Chatterjee, 2019) [3]. Slope ceilings can generate similar effects. These practical problems can be addressed by including corrections in SMART sprinkler activation algorithm. The separation of fire detection from sprinkler activation also opens up the possibility of using different kinds of sensors or a network of sensors, including wireless sensors, infrared flame detectors and video image-based detection. In principle, optical sensors provide the fastest response and potential 3D locating of the fire without being affected by the ambient air flow, if the field of view allows direct transmission of flame radiation. In contrast, smoke and heat detectors are subject to the limits of convective flow and impact of ambient air flow, which can be mitigated by placing either wired or wireless detectors in the rack (i.e., ceiling-only SMART sprinkler with in-rack detection).

Figure 3. Fire development in a 7-tier rack storage test of cartoned unexpanded plastic (CUP) commodity.
Validation Testing and Reliability

After confirming its fast activation and accurate location, the prototype SMART sprinkler was tested in a series of large-scale fires using cartoned unexpanded plastic (CUP) commodities up to seven tiers of rack storage. In all fire tests, the sprinkler protection was triggered based on two conditions: (1) trigger of at least one smoke detector; and (2) temperature rise > 5°C. When these conditions were met in the 7-tier test, the flames barely touched the second tiers, in contrast to the traditional sprinkler where flames touched the 40-ft (12-m) ceiling. The flames never exceeded the rack storage height and the target array across a 4-ft (1.2-m) aisle was never ignited. Within 20 minutes of ignition, the fire was nearly extinguished. The SMART sprinkler not only suppressed the fire with less water, but also did so with much less fire and water damage. Recent large-scale fires tests conducted at FM Global demonstrated that water usage can be reduced by > 50% for a variety of protection scenarios including low-pile storage with high ceiling clearance and high rack storage using in-rack detection.

![Figure 4. Comparison of water demand between SMART and traditional sprinklers.](image)

Based on the rack storage fire tests completed so far, the SMART sprinkler has several advantages over the traditional sprinkler:

- Detects fire very early in its development.
- Determines the fire location accurately.
- Simultaneously activates a group of sprinklers upon fire detection and location.
- Controls or suppresses the fire using less water.
- Results in less fire and water damage.

In addition to protecting HCFs, this technology is useful when the available water supply is limited. The key to using fewer sprinklers and less water is targeted water delivery. This advantage can also be vital from a cost perspective. If fire protection can be achieved with less water, users may be able to avoid the construction of large storage tanks or the installation of expensive pumps. Building owners may even be pleased with the “green” aspects of using less
water. From an economic standpoint, locational accuracy and early detection combine to reduce the number of sprinklers that may be needed to achieve the same effect. Where a traditional design might require 12 or even 30 sprinklers, the same results might now be achieved using fewer than 10 sprinklers with even lower loss expectancy.

For reliability, FM Global Research has analyzed the availability of the prototype SMART sprinkler system (Chatterjee, 2016) [4]. The reliability analysis starts with an understanding of the system working mechanism so that a failure model and effect (unavailability) tree can be developed. This tree outlines the system components and their logic relationships to reflect relevant failure modes and effects, which, with component reliability data, feed a statistical model to compute the system availability subject to a given inspection, testing and maintenance (ITM) frequency. The results show that with sufficient ITM frequencies, the SMART sprinkler can achieve comparable reliability levels to those of traditional sprinklers. The availability aspect is also important to the certification of the SMART sprinkler system, which should also include component testing, algorithm assessment and large-scale fire testing. Because the SMART sprinkler is new technology, one should be cautious about where and how it will be used. For instance, the exposure of the electronic components could damage the system affecting fire detection and sprinkler activation, ambient air flows could cause significant deviation to locate the fire origin using ceiling smoke and heat detectors, and obstructions could interfere with optical or image-based detectors. Furthermore, the working mechanisms of any new system will be carefully studied to rectify any unforeseen vulnerabilities.

Future of SMART sprinkler

The future of the SMART sprinkler is promising not merely because it delivers where a traditional sprinkler cannot, but because of its ability to suppress fires faster with less damage and less water. The potential reduction of water demand by at least half while decreasing fire and smoke damage could be a huge advantage, especially for occupancies storing high-value products, or for regions with limited water resources. Furthermore, SMART sprinkler fundamentally changes the way of detecting and locating a fire, as compared to a slow heat detector relying on buoyant flow as the choice for a traditional sprinkler. These advantages, together with the intelligent activation of multiple sprinklers at the same time will allow fire protection to reach its ultimate goal of extinguishing a fire as early and as locally as possible.

References


Fire Safety Challenges of ‘Green’ Buildings and Attributes: Summary Findings

Brian J. Meacham, Meacham Associates, USA
Margaret McNamee, Lund University, Sweden

Overview

In 2012, the Fire Protection Research Foundation (FPRF) supported a literature review related to fire safety challenges of ‘green’ (sustainable) building materials, systems (technologies) and features [1]. The aims of that work were to: identify documented fire incidents in ‘green’ buildings; define a specific set of elements in ‘green’ building design, including configuration and materials, which, without mitigating strategies, increase fire risk, decrease safety or decrease building performance in comparison with ‘traditional’ construction; identify and summarize existing best practice case studies in which the risk introduced by specific ‘green’ building design elements has been explicitly addressed; and compile research studies related to incorporating building safety, life safety and fire safety as an explicit element in ‘green’ building indices, identifying gaps and specific needed research areas.

In the eight years since the 2012 report was published, there have been several major fire events which involved ‘green’ materials, systems and features (collectively, ‘green’ attributes) in buildings, including the tragic Grenfell Tower fire in London (involving combustible insulation); the Dietz & Watson cold storage warehouse in Delanco, New Jersey (involving photovoltaic panels, combustible insulation); and the 2019 energy storage system (ESS) explosion and fire in Arizona. While each of these can be categorized in many ways, they (and many others) include materials, systems and features that are considered ‘green’ or sustainable. Additionally, since 2012, there has been significant research into the fire performance of a wide range of ‘green’ attributes of buildings, and numerous changes and/or additions to regulations, standards and guidance around managing and mitigating associated fire hazards and risks. Further, new ‘green’ attributes continue to be developed and implemented, which could present fire hazards or risks if unmitigated.
In response to the major advances that have taken place since 2012, research was conducted to assess the changes which have occurred. The resulting report [2] presents a comprehensive review of how the landscape of fire safety challenges of ‘green’ attributes of buildings has developed since 2012. The report reflects a global information search of more than 400 sources covering: fire events involving ‘green’ and/or sustainable building materials, systems and features; emerging ‘green’ building materials, systems and features; and research, regulatory changes, engineering approaches, risk mitigation strategies, and firefighting tactics associated with fire challenges with ‘green’ and/or sustainable building materials, systems and features. While the research is comprehensive in scope, it is not exhaustive in detail, given the extent of advancement in these areas which has occurred since 2012. The report notes that while significant advancements have been made, gaps remain, and presents several recommendations for additional research and development. These recommendations are summarized below.

**Recommendations for Additional Research and Development**

- **Integration of ‘green’ (sustainable) attributes of buildings into fire incident reporting systems.** While more fire incident data are available than was identified in 2012, there remains significant gaps in reporting on fire ignitions and contributions of ‘green’ building materials, systems and technologies, and how sustainable planning and building features may have impacted the severity of a fire or the response of the fire service. While some major events such as the Grenfell Tower fire capture attention for some time, it may be that there are hundreds of fires involving sustainable building materials, systems (technologies) and features that are not identified, and therefore not available to inform mitigation options.

- **More robust and appropriate test methods, which yield engineering data, for assessment of material, component and systems performance.** Closely related to the above, while some progress has been made on better understanding fire performance of ‘green’ attributes of buildings, some of the current standardized testing may not capture the fire safety hazards and risks of the materials, systems and technologies in use (i.e. real life scenarios) well enough. Furthermore, the outcomes of the tests are not always conducive to engineering analysis through computational methods; and given the cost of mid- and full-scale testing, relevant data for the extrapolation or interpolation of results using engineering methods, are not developed. The fire performance of complex façade systems is but one example. Data for engineering analysis is needed for all components, and the means to assess real-scale system performance is required.

- **Integration of fire performance considerations into sustainable materials, technologies and features research and development.** As emerging technologies such as carbon capture systems, new structural materials, BIPV and more are developed, fire safety needs to be at the front end of the design process, and not an afterthought. Consider what happens as building integrated photovoltaics system (BIPV) technology becomes fully integrated into façade systems, providing a potential source of ignition that is
continuously available. In product design, like building design, the cost to mitigate at the end is much higher than at the outset. This will require a change in thinking within the product and building design communities, although this can build on a tradition of product design for the environment adopted in consumer products previously.

- **Robust risk and performance assessment methods and tools, which are founded on broad expert stakeholder knowledge and experience, available data, and expert judgment where data are lacking.** One could argue that by definition emerging technologies will have many unknowns. While testing, such as component level fire testing, can provide insight into part of the scenario, it may be insufficient to understand the overall fire performance. Risk-informed performance-based methods are needed to provide insight into the range of possible realizations of complex systems designs, and to inform mitigation strategies to control the risks to tolerable levels. Without all of the physical or statistical data needed to make judgements with very small bands of uncertainty, expert judgment, broad stakeholder deliberations, and use of available data will be needed. Methodologies that appropriately integrate these components will be essential.

- **Better tools for holistic design and performance assessment, taking advantage of BIM and other technologies that are defining the future of the construction market.** Fire safety design is not, and should not, be an isolated practice. Rather, it is part of a holistic design of a building. Better analysis and design tools for support of multi-dimensional performance assessment will be needed, and more use of technologies such as BIM, which are already widely used in the design practice, will be needed. As the industry moves to modular, or prefabricated prefinished volumetric construction, analysis and design decisions will be made ‘in the shop’ prior to manufacturing of components for shipment to the site and assembled into a finished building. Not only will the design technologies be essential, but also the means to assure the assembled building has addressed key issues, such as fire protection of connections, fire protection of void spaces, and the like. If such a building has issues that need to be ‘fixed’ after construction, the costs could be significant.

- **Transition to more holistic, socio-technical systems approaches for building regulatory systems, which consider the diversity of societal and market objectives for building design, construction and lifetime operation.** The current building regulatory system remains largely structured following the ‘regulation by event’ approach that has been used for the past 100 years. Regulatory development is undertaken largely by disparate experts working in individual silos with the hopes that the outcome is a horse and not a camel. There are numerous societal and market objectives for building design and construction, and there should be requirements for lifetime performance in operation, across a wide spectrum of aspects, including sustainability and fire resiliency. Investigations into fires such as the Grenfell Tower point in some ways to how fortunate we are that catastrophic fire remains a relatively rare event. Evolving the building regulatory system to a more socio-technical systems approach can help better identify and address the diversity of objectives a building is expected to achieve throughout its
lifetime. This includes all aspects of the regulatory system, including regulations, standards, compliance, etc.

- Further development and articulation of the SAFR building concepts and its societal and economic benefits. The concept of Sustainable And Fire Resilient (SAFR) structures has been proposed as a way to better integrate sustainability and fire safety performance objectives in building design and performance. A ‘green’ building is not so ‘green’ if it burns down and needs to be reconstructed. A fire sprinkler system is not just a life safety system, but is a means to minimize environmental impact should a fire occur. Steps need to be taken to develop concepts that deliver on both objectives in a holistic manner.

Additional details are available in the full 150-page report, *Fire Safety Challenges of ‘Green’ Buildings and Attributes*, which can be downloaded for free from the Fire Protection Research Foundation (FPRF) website [2].

**Acknowledgements**

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**References**


Analysis of Travelling Fires and Comparison to the Travelling Fire Methodology

Vinayagum Reyalen Ramsamy¹, Emmanuel Annerel²,³, Karim Van Maele², Georgios Maragkos³ and Bart Merci³

¹International Master of Science in Fire Safety Engineering (www.imfse.be) - reyalenramsamy@gmail.com

²Etex Innovation and Technology Centre, Etex Building Performance, (www.etexgroup.com)

³Ghent University – UGent; Faculty of Engineering and Architecture; Department of Structural Engineering and Building Materials

Context

As open-plan compartments become increasingly common in the built environment, it has become important to understand travelling fire behaviour in the context of fire safety. In contrast to the behaviour of a fire in a small compartment, travelling fires are characterised by a flame front that progressively spreads across the enclosure, leading to regions of high and low temperatures, at different points in time and space. Such a fire behaviour has been observed both experimentally in Cardington [1] and Dalmarnock fire tests [2], as well as in accidental fires in large compartments, such as the Ghost Ship Warehouse Fire in the U.S.A in 2016 [3], TU Delft in the Netherlands in 2008 [4], the Windsor Tower in Spain in 2005 [5] and the World Trade Center in New York in 2001 [6]. Although the parametric temperature-time curve in Eurocode 1 [7] addresses the transient nature of the temperature within a compartment, it does not capture important phenomena related to travelling fires, such as a pre-heating phase of structural elements due to smoke movement prior to flame impingement.

Bearing in mind that sound fire safety design of structural elements relies upon a realistic time-temperature curve, this study attempts to evaluate the adequacy of new fire models proposed in literature, such as the Travelling Fire Methodology (TFM) [8], using CFD analysis. In this paper, the findings of a numerical study of travelling fires using the Fire Dynamics
Simulator (FDS, Version 7.6.0) [9] software are summarized. Different ventilation and geometry configurations as well as dynamic ventilation changes during the fire event are simulated; a comparison of some of the findings is performed with respect to what is suggested by the TFM. The full version of the MSc thesis can be found on [10].

**FDS Simulations Set-up**

To capture travelling fire behaviour, a compartment of 40m by 10m was constructed, based on a previous CFD study on travelling fires [11]. The position and sizes of the openings were varied to investigate their impact on the fire spread. The cases studied are summarised in Table 1. For computational reasons, the mesh size used was set at 20 cm. It is acknowledged that the 20 cm mesh cannot provide accurate temperature predictions (i.e. the maximum temperatures are underestimated) but allows to study the temperature-time trends observed in travelling fires. A mesh sensitivity study and its implications are given in [10].
<table>
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<th>Front View</th>
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<td>4 m</td>
<td>40 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Larger Opening</td>
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<td>4 m</td>
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<td>10 m</td>
</tr>
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<td>Single Opening</td>
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<td>Open ended compartment</td>
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<td>40 m</td>
<td>10 m</td>
<td>4 m</td>
<td>40 m</td>
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</tbody>
</table>

The individual fuel packages were modelled based on the burning characteristics of wooden pallets. A critical temperature for ignition of wood (set to 300°C) is used as the trigger for flame spread between fuel packages: each fuel package ignites automatically once the surface temperature reaches the critical value.

### Analysis of Travelling Fire Behaviour as Function of the Ventilation Openings

The adiabatic surface temperature at several points situated at the ceiling height were recorded and analysed. The comparison of different ventilation opening conditions revealed significantly disparate temperature-time profiles for the same fuel set-up (Figure 2). Multiple cases exhibited a double temperature peak, attributed to the presence of a closed space at the end of the compartment. In such cases, the first peak corresponded to the moving flame front lying directly below the measurement device, while the second was caused by a ‘localised flashover’ as the fire reaches the end of the compartment.
Figure 1 Adiabatic Surface Temperature for different ventilation conditions showing varying temperature-time profiles. The measurement device is located at the centre of the compartment and at ceiling height (4m).

Figure 3 clearly shows how smoke accumulation at the closed end of the compartment lead to rapid ignition of multiple fuel packages at once (t=75min) causing severe flame impingement on the ceiling. The end-of-compartment flashover is absent in the simulation with an open-ended enclosure resulting in a single temperature peak: minimal amounts of smoke are trapped within the compartment. Instead, a bidirectional flow regime was observed as shown in Figure 4.

Figure 2 Temperature slice of compartment (baseline case) showing accumulation of smoke in the closed ends of the compartment leading to localised flashover of unburnt fuel packages (t=75min) (denoted by dotted polygons)
Compartment with closed end leads to hot smoke accumulation (Baseline case)

Open-ended compartment

Figure 3 Flow field at end compartment for an open-ended compartment and compartment with closed end.

One of the simulations modelled the effect of an initially closed window, assumed to break, and fall out completely upon reaching 300°C. The results were compared with those of the same compartment with fully open windows throughout the fire. The comparison showed temperature differences of up to 300°C between the two scenarios, emphasizing the strong impact of ventilation conditions, not only at the start of an enclosure fire, but also during the course of the fire event. The findings also identify this behaviour as a potential barrier to developing reliable temperature-time predictive methodologies when ventilation conditions are not considered.

Figure 4 Temperature-time profiles of compartment with closed breakable windows v/s compartment with opened windows. Higher peak temperature and shorter burnout time observed in initially closed breakable window case.

Analysis of the fire progress of different scenarios simulated showed that the fire spread rate was not constant during the fire event. Rather, it varied significantly depending on local
ventilation conditions. In Figure 6 a), it varied from 6.7mm/s and peaked at 40mm/s when the flame front approached the openings, whereas in b) the fire spread rate remained relatively constant at 6.7mm/s during the entire fire event.

![Diagram of ventilation conditions]

Figure 5 Mapping of flame front at different time stamps. The light blue border indicates the position of the windows. The tunnel-like geometry in b) leads to a more uniform fire spread rate because of a steady directional flow regime is established.

**Travelling Fire Methodology (TFM)**

The Travelling Fire Methodology (TFM) allows to predict the temperature-time evolution of the simulated scenarios. The methodology of [12] was applied, utilising a main equation that governs the temperature at a point of interest, taking into account the position of the fire within the compartment:

\[
T_{\text{max}}(x, t) = T_{\infty} + \frac{5.38}{H} \left( \frac{L L^* W Q^*}{x + 0.5 L L^*} - \dot{x}_t \right)
\]

Where  
\( T_{\text{max}}(x, t) = \text{Far field temperature at point } x \text{ at time } t \)  
\( T_{\infty} = \text{Ambient temperature, (K)} \)  
\( H = \text{Height of compartment, (m)} \)  
\( L = \text{Length of compartment, (m)} \)  
\( W = \text{Width of compartment, (m)} \)  
\( L^* = \text{Dimensionless fire size depending on location of the leading edge of the fire} \)  
\( Q^* = \text{Heat Release Rate per unit area, (KW/m}^2) \)  
\( x = \text{Horizontal distance between point of fire origin to point of interest, (m)} \)  
\( \dot{x}_t = \text{Location of the leading edge of the fire relative to place of fire origin, (m)} \)

Comparison of the outcome of Eq. (1) to the CFD simulation results revealed that the TFM produced reasonable predictions as long as the actual fire spread rate remained relatively constant during the entire fire event, which was only the case in the open-ended compartment scenario. TFM yielded underpredicted far-field temperatures due to its inherent assumption of an unconfined ceiling (relying upon Alpert’s correlation). The TFM could not predict the second temperature peak observed in the scenarios with closed ends, thus diverging significantly from the simulation results.
Figure 6 Temperature time profile and TFM prediction for open-ended compartment and baseline case showing that the scenario with a uniform fire spread rate also generates more realistic predictions. Note the end of compartment flashover is not predicted by the TFM and is out of phase due to the varying flame spread rate.

Conclusions

Having inferred from numerical results the strong influence of ventilation conditions on both the extent and speed of fire spread, it is evident that further research and experimental work is needed to reinforce current temperature-time predictive methods. This study showed that events such as window breakages could significantly change the fire development, reiterating the complexity of fires in large enclosures. Although it is acknowledged that the computational requirements are limiting factors in the accuracy of the numerical simulations, the TFM did not conservatively predict the thermal exposure of the ceiling in the simulations as run. While the inferences made so far are substantiated through the numerical study, the need for validation experiments coupled with refined simulations are critical to a better understanding of travelling fires.

Acknowledgment

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References


Introduction

During the last decade, more countries have become considerably affected by wildfire. In Europe for example, northern countries such as Sweden, Norway and Scotland realized that they are not immune to this phenomenon. In Australasia, recent exposure of New Zealand’s urban communities to destructive wildfires has prompted local researchers to design new multidisciplinary research projects, ultimately aiming to prepare New Zealand society to face more severe Wildland-Urban Interface (WUI) fires. This article briefly discusses the state of the problem and describe some of the current and upcoming local research projects around this topic.

The year 2020 was particularly devastating in terms human lives and property lost around the world. In Australia alone, 3000 houses were destroyed and 33 people killed during the catastrophic 2019/2020 fire season [1]. While in neighbouring New Zealand the level of destruction was not at the same scale, recent fire events set off the alarms and raised questions about how devastating future fire seasons will be, and how well prepared the country is to face it [2, 3]. 2016/2017 New Zealand WUI wildfire events, including Port Hills fire, resulted in the most destructive fire season in a century [4]. Very recently, Lake Ohau fire [5] showed a comparable destructive power. Those events alone might not be sufficient to define a significant trend, but considering the vulnerability of New Zealand to climate change [6, 7] and expansion of wildland-urban mixed environment [8], they constitute a clear sign of a new growing risk that needs to be addressed. Increasing of climate severity (e.g. hotter and dryer seasons) in New Zealand will potentially result in more intense and frequent fires, due to factors such as dryer fuel vegetation and greater wind speeds. Likewise, expansion of urban presence in wildland environments will considerably increase the potential damage of fires and is expected to raise the likelihood of vegetation ignition.
Several organizations in New Zealand, including the University of Canterbury, Scion and Fire Research Group Limited are currently cooperating to gain a holistic understanding of the WUI problem, which is essential to support policymaking and firefighter protocols that protect New Zealand communities. WUI computational modelling of fire behaviour at the fuel-atmospheric dynamic interface is one of the research challenges that will be addressed through a collaborative research project starting in 2021. The research has two interconnected objectives aimed to better understand fire behaviour at the WUI,

1. Numerical simulation of wind turbulence associated with real atmospheric boundary layer development (fig. 1a), and
2. Simulation of fire behaviour for real New Zealand fuel and urban canopy types (fig. 1b).

The research team aims to dynamically couple the turbulence resolving Parallelized Large Eddy Simulation Model (PALM, https://palm.muk.uni-hannover.de/trac) with the WUI module included in the Fire Dynamics Simulator (FDS) developed by NIST and US Forest Services [9]. The coupling will allow multiscale atmospheric boundary layer turbulence interacting with the physical and chemical dynamics of the WUI fuels. This will be demonstrated in New Zealand high-risk WUI wildfire scenarios, supported by state-of-the-art measurements of fire spread rate, vegetation distribution, topography characteristics and atmospheric conditions from an ongoing experimental campaign [10]. Results will be valuable to assess the ability of simulation tools to model realistic New Zealand WUI fire scenarios, as well as to support the development of a primary risk assessment framework, with potential to be used as guideline by countries experiencing a similar situation.

![Figure 1. Modelling of fire-atmospheric interactions: a) Numerical simulation of wind turbulence associated using PALM and b) Simulation of wildfire behaviour using FDS.](image)

Flammability properties of several types of New Zealand WUI bush vegetation will be experimentally and numerically characterised from small scale through Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), to medium and vegetation scale using cone calorimeter and bush-to-bush propagation schemes. Outputs of this project will result in a detailed database of vegetation flammability characteristics, able to support implementation of WUI fires protection strategies, advanced fire severity mapping and regulatory measures in New Zealand.
From a global point of view, results from these projects are expected to help clarifying the nature of the risk, providing momentum to local and international WUI fires research efforts, and to support future initiatives aiming to increase the level of safety of New Zealand society.

References


Compliance Road-map for the Structural Fire Safety Design of Mass Timber Buildings in England

By: Danny Hopkin, OFR Consultants, UK; Michael Spearpoint, OFR Consultants, UK; Carmen Gorksa, Stora Enso, UK; Harald Krenn, KLH, Austria; Tim Sleik, Binderholz, Austria; and Martin Milner, Structural Timber Association, UK.

Introduction

Timber structures are resurgent due to environmental drivers, with an increasing number of tall and complex buildings being conceived that incorporate mass timber, either for the entirety of the structural frame or in parts of hybrid structures (often incorporating steel and/or concrete components). Timber structures are being designed and delivered at a pace that can potentially go beyond current levels of knowledge and the competency of fire safety engineers. In a project funded by three major European cross-laminated-timber (CLT) suppliers (Stora Enso, Binderholz and KLH) through the Structural Timber Association (STA), the need for clarity on how mass timber buildings can satisfy the requirements of building regulations across the UK has been identified. OFR Consultants (OFR) have been engaged as the lead research consultant on the project, with the support of an independent stakeholder review group. A compliance road-map [1] has been developed which serves to guide designers towards the most appropriate route for compliance with English regulatory requirements concerning structural performance in the event of fire. This article summarises the context and background to the development of a consequence-based compliance design tool developed in support of the rational design of mass timber buildings.

The problem and need

Timber is a combustible material. Where it forms large parts of a fire compartment’s surface area and can contribute as a source of fuel, it can change the fire dynamics within. Relative to using non-combustible materials this may lead to: higher heat release rates, increased compartment gas temperatures, higher incident heat fluxes to structural elements, prolonged fire duration (Figure 1 – Conceptual illustration of heat release rate vs. time in inert or combustible enclosures, with or without self-extinction), more severe external flaming, etc. [2].
The fire dynamics implications can undermine assumptions underpinning fire resistance paradigms for cases where the structure must survive burn-out and the structure is not prevented from contributing as a source of fuel [3]. This places a challenge with the designer to consider how regulations pertaining to structural performance in the event of fire can be satisfied, and what design evidence must ultimately be produced.

Figure 1 – Conceptual illustration of heat release rate vs. time in inert or combustible enclosures, with or without self-extinction.

**Structural fire performance objectives**

Concerning the performance expected of the structure in the event of fire, the Building Regulations in England set out the minimum expectations under a life safety purview, with Regulation B3(1) stating:

“The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period."

Whilst speaking to periods of time, the wording of Regulation B3(1) does not explicitly define the duration of structural stability required in the event of fire. With respect to ref [4], the structural fire safety performance objectives for a building can vary in function of the consequences of fire induced collapse. This is elaborated through a bifurcation of objectives as illustrated schematically in Figure 2.
Guidance- and performance-based routes to compliance

For most common and straightforward building situations, Regulation B3(1) is addressed through the adoption of ADB [5], [6], or similar codes [7] [8]. Therein, fire resistance ratings are
recommended for elements of structure in function of building size and use. Subsequently, elements are either designed to inherently achieve, or are protected to achieve, the recommended fire resistance rating. In the case of mass timber elements, fire resistance would commonly be demonstrated through the calculation methods in BS EN 1995-1-2 [9] or through appropriate test evidence. Once these ‘fire resisting’ elements are formed into a structural system, that structural system can be said to satisfy Regulation B3(1).

Following ADB or similar is not the only means of satisfying the relevant requirements of the Building Regulations. Alternative routes exist and these are discussed in BS 7974 [10] and the associated suite of Published Documents. For some more complex situations, such as those falling outside of the scope of guidance, alternative fire engineering approaches may be the only means of demonstrating compliance with the Building Regulations.

Mass timber and the route to structural fire safety compliance

The proposed STA compliance road-map posits that the relevance of a guidance-based route to compliance depends upon the structural fire performance objectives (per Figure 2):

- **Provision of adequate time:** the structure having a reasonable likelihood of surviving the full duration of a fire is not a prerequisite for compliance with Regulation B3(1). Therefore, following the fire resistance guidance in ADB, for example, can likely result in an adequate level of safety and compliance with Regulation B3(1) subject to elements being designed appropriately for the recommended fire resistance rating (e.g., through application of BS EN 1995-1-2 [9]);
- **An adequate likelihood of surviving burn-out:** unless the structure is prevented from contributing as a source of fuel, applying the fire resistance approach (for example in ADB) cannot guarantee that Regulation B3(1) is satisfied. Preventing the structure from contributing as a source of fuel will require encapsulation. Where the structure is permitted to become involved as a source of fuel, a performance-based route to compliance is likely the only means of demonstrating compliance with Regulation B3(1).

Mass timber fire safety design solutions

Differing design solutions exist for mass timber buildings which will have implications for the route to compliance. These can broadly be grouped into three categories:

- Exposed – the structural elements are exposed from the outset of the fire by design;
- Partial protection - the structural elements are behind a protective lining. However, this lining does not avert pyrolysis for the full duration of the fire;
- Encapsulation - sufficient protection is provided to the underlying structure / substrate to mitigate the onset of pyrolysis until burn-out.

In both the case of “exposed” and “partial protection”, it should be assumed that the structure will become involved as a source of fuel at some point in a fire. Application of these routes requires demonstration by a competent fire engineer with relevant experience that the structure has a reasonable likelihood of surviving burn-out with due consideration of: the impact of the combusting structure on fire development, the ability of the structure to undergo self-extinction, and the ability of the structure to support the applied loads during and beyond the fire event. A performance-based assessment may be augmented by project specific testing.
in support of demonstrating that self-extinction is achieved and that the structure subsequently remains stable.

Irrespective of the solution presented, the (residual) structural elements must be capable of supporting the load either for the duration of the fire resistance period or for the full duration of a fire, as relevant to the route of compliance.

A consequence-based design tool for compliance

Failure consequences due to fire drive the structural performance objectives, and are differentiated in guidance addressing general structural design (Approved Document A – ADA [11]) and fire safety design (Approved Document B - ADB) through the use of consequence classes (Table 1) and trigger heights, respectively. Whilst the two Approved Documents (ADA and ADB) can appear unrelated, it is considered appropriate in the context of this work that the ADA consequence class system serves as a boundary on the application for fire resistance guidance. However, trigger heights cannot be disregarded altogether as history highlights their role in signifying transitions in means of escape, fire fighting, etc. [12].

Considering failure consequences as the primary factor (and trigger heights as a relevant factor), a general design tool has been adopted as per Table 1 to assist designers in identifying the most appropriate route to compliance for a mass timber building project.

Table 1 - Consequence classes per Annex A of BS EN 1991-1-7 [13] and consequence-based guidance on route to compliance for mass timber buildings (life safety).

<table>
<thead>
<tr>
<th>Consequence Class</th>
<th>Consequences of failure</th>
<th>Typical building type and occupancy relevant to mass timber</th>
<th>Permissible compliance route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Guidance-based1</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>• Single occupancy houses not exceeding 4 storeys</td>
<td>Yes5</td>
</tr>
<tr>
<td>2A</td>
<td>Low to medium</td>
<td>• 5 storey single occupancy houses</td>
<td>Yes2,5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hotels not exceeding 4 storeys</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Flats, apartments and other residential buildings not exceeding 4 storeys</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Retail premises not exceeding 3 storeys of less than 1000 m² floor area in each storey</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Single storey educational buildings</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• All buildings not exceeding 2 storeys to which the public are admitted, and</td>
<td></td>
</tr>
<tr>
<td>Building type and occupancy</td>
<td>Limit on upper floor level above lowest ground level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>11 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1 – for England, the guidance-based approach is documented in, for example, ADB which specifies the recommended fire resistance rating for elements of structure. Elements are then demonstrated as having adequate fire resistance through appropriate testing and/or calculation methods, e.g. BS EN 1995-1-2.

Note 2 – subject to the purpose group specific height limitations set out below, otherwise Note 3 applies:
<table>
<thead>
<tr>
<th>Category</th>
<th>Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hotels and other residential</td>
<td>11</td>
</tr>
<tr>
<td>Offices &amp; mercantile</td>
<td>18</td>
</tr>
<tr>
<td>Assembly and recreation</td>
<td>7.5</td>
</tr>
<tr>
<td>Education / schools</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**Note 3** – only applicable to mass timber afforded encapsulation with the lining capable of averting pyrolysis for the full duration of the fire resistance period.

**Note 4** - Consequence Class 3 structures should be subject to a project-specific system risk assessment considering all relevant hazards, per ADA and in satisfaction of Regulation A3. This necessitates a performance-based assessment in all cases.

**Note 5** – No limitation is placed on the design solution, i.e. exposed, partially protected or encapsulated structures are permissible.

**Note 6** – Number of storeys includes ground floor.

**Conclusions**

The compliance road-map [1] summarised in this article enables those involved in the design of mass timber structures in England to assess the likely most appropriate compliance pathway to meet Building Regulation B3(1) in function of the failure consequences and the preferred design solution. It will ensure consistency in how mass timber building design is approached and will assist approval authorities in the scrutiny of designs. It should be stressed that other hazards exist when building with mass timber, in particular those concerning internal and external fire spread, as discussed in more detail elsewhere [14], [15]. The developed road-map should, therefore, be applied in support of a holistic fire strategy, developed by competent individuals with relevant experience, which captures all relevant implications of building with mass timber.

The next stage of the project is to collate data on the performance of CLT in enclosure fires. Small-scale experimental work is on-going to gain a more thorough understanding of the comparative performance of different CLT lamella and glue arrangements from the sponsoring suppliers. This will be followed-up by large-scale experiments that will investigate how these arrangements affect the dynamics of fire development in larger enclosures such as open-plan offices where a ceiling is constructed of exposed CLT panels. This work has been delivered as part of a collaborative project run by the STA, with all project outputs and background research being made available via the STA website ([http://www.structuraltimber.co.uk/sectors/clt-special-interest-group](http://www.structuraltimber.co.uk/sectors/clt-special-interest-group)).

**Acknowledgements**

The project team would like to acknowledge the insights of the stakeholder review group, in particular the contributions of: Luke Bisby (University of Edinburgh), Tom Lennon (BRE), Neal Butterworth (DFC), Lynsey Seal (London Fire Brigade) and Charles Ellie-Romeyer (Ministry of Housing, Communities and Local Government).
References
AAMKS - Integrated Cloud-based Application for Probabilistic Fire Risk Assessment

By: Adam Krasuski, The Main School of Fire Service, Poland. Simo Hostikka, Aalto University, Finland

Introduction

Available models of fire risk assessment can still hardly be used for practical engineering problems. They are mostly loosely integrated, complex, computationally demanding applications, and require additional pre- or post-hand-calculations. However, the latest achievements in computer science enable establishing an easy-to-use web-application with access to enormous computing power in a cloud requiring minimal management effort.

In this article, we present a new tool for probabilistic fire risk assessment called Aamks. Our goal is to build an easy-to-use, science-based, practical engineering tool to support building design in day-to-day work. To meet the overall goal, we aim at working out an integrated, web-based application with computational efficiency and scalability allowed by cloud computing.

Aamks performs a stochastic analysis of life safety in building fires using deterministic models for fire and evacuation and stochastic sampling of the uncertain input parameters. In day-to-day work. To meet the overall goal, we aim at an integrated, web-based application with computational efficiency and scalability guaranteed by grid computing. The integration proposed in Aamks allows for creating on-demand services feasible to calculate the computationally expensive quantitative fire risk analysis in the convenient web application.

Model Description

Aamks performs a stochastic analysis of life safety in building fires based on deterministic models for fire and evacuation, and stochastic sampling of uncertain or variable input parameters [1]. The main phases of the modeling are:

1. Problem definition. The building configuration and scope details are identified and encoded into the CAD model. Then the set of parameters reflecting occupancy, building and environmental characteristics are defined.
2. Monte Carlo sampling. The input parameters for the model that are uncertain or variable are sampled from defined probability distributions.
3. **Fire and evacuation simulations.** The input vectors are distributed across nodes of grid architecture. Each node performs deterministic modeling of a single fire scenario defined by the Monte Carlo sampler. The evacuation simulations are performed on top of data obtained from fire modeling; that way the fire and its environment affect the evacuees.

4. **Data post-processing.** The model output is presented in the forms of individual as well as societal risks. Other available outputs include the distributions of available safe egress time (ASET) and required safe egress time (RSET), failure probability, hot layer height distribution, visibility, as well as maximal temperature.

The general idea of Aamks is based on the approaches proposed in [2,3] -- stochastic simulation on zone models. However, we expanded the approaches by deploying the fully-featured evacuation model. Fire and evacuation are modeled consecutively for each model implementation, allowing quantification of the safety level of people by means of a Fractional Effective Dose (FED) [4]. The tool consists of eight modules presented in Figure 1:

1. **A-GUI:** a web application for user input and results visualization. The workflow needs to be commenced using a CAD model of the building. Currently, Aamks allows two methods: i) AutoCAD plugin or ii) a-painter, our own editor. The user’s interaction requires only providing the CAD model of the building, setting a short list of meta parameters (e.g. the occupation type), starting the simulations and later interpreting the results. The administrator needs to install Aamks on the server and the user interacts with Aamks via a web browser, so it requires no configuration on the user’s part.

2. **A-GEOM:** module for performing geometry processing. The model and parameters defined in A-GUI are to be converted to an internal Aamks format which is needed for topology reasoning and other tasks.

3. **A-MC:** stochastic producer of input files for A-FIRE and A-EVAC. Aamks has a library of distributions for each of about dozen input parameters that describe various aspects of the scenario. Both Simple Random Sampling (SRS), as well as Latin Hypercube Sampling (LHS) methods can be used.

4. **A-GRID:** managing computations on the grid/cloud. Obviously, a significant computational power is needed to run simulations. Therefore, Aamks is meant to be run in a cluster or grid environment. The computers that run the simulations are called nodes or workers.

5. **A-FIRE:** fire simulations models. Aamks currently uses the CFAST zone fire model for the fire development and smoke spread simulations, and Ozone for the thermal response of steel construction. These are zone models that enable quick (in the meaning of computation costs) exploration of the space of possible fire scenarios. After the fire simulation, the output files, which are generally unsuitable for massive data access queries, are processed for fast tenability information queries in the consequent stage.

6. **A-EVAC:** simulation of human movement and states. A fully featured evacuation model has been developed [5], which is based on navigation meshes for global wayfinding and the Optimal Reciprocal Collision Avoidance model for collision avoidance. In addition, evacuees are affected by smoke which restricts visibility and affects their speed. Finally, the fire consequences are measured as the Fractional Effective Dose (FED). In the case of a traumatic injury, the temperature inside construction elements is calculated using the OZone software. Once the temperature has achieved the critical value, the collapse of the building is assumed.

7. **A-RESULTS:** post-processing the results and creating the content required for reports. The module summarizes data from the deterministic fire and evacuation simulations,
creates output probability distributions, and presents them as collections of charts and tables for risk assessments, such as the FN curves.

8. A-VIS: simulation animation visualization. This module enables the inspection of specific simulations. The results are animated to show the ways the evacuees move and how toxic gases affect their condition.

Figure 1. General overview of the Aamks model and workflow

Risk Model and Metrics
The risk calculated in the model is summarized in an event tree structure. There are currently three primary factors used for the calculation of consequences in Aamks: toxicity, heat and traumatic injury. The toxic injury model is based on the calculation of FED and its further ranking [5]. The thermal injury model is based on the FED of convected heat accumulated per minute as defined in NFPA502. The traumatic injury model is of a rather rough nature and is based on an exceeding of the temperature of construction stability with respect to evacuation time.

In the majority of simulations, the majority of consequences arise from FED. It is based on the predicted concentrations of carbon monoxide, hydrogen cyanide, hydrogen chloride, carbon dioxide, and oxygen. The FED value equal to one is interpreted as a 50\% of chance of fatality and a high consequence (H). The response to lower or higher values of FED is translated into fatality by using log-normal probability distribution function following ISO 13571. The probability of fatality is calculated independently for all the evacuees. Next the final individual risk of death is calculated as a complement probability that nobody dies. Sublethal effects, also based on the FED, are broken down into: minor (N), low (L) and medium (M).

The risk is calculated as a share of the number of simulations that resulted in a given consequence type to the total number of simulations. It represents the annual risk of death to which specific individuals are exposed. This means the risk to a person in the vicinity of a threat, including the type of consequences and the probability of consequence occurring. The obtained values can be further evaluated using absolute values defined for example in standards PD7974-7, engineering knowledge [6] or set of approaches for relative methods presented for example in [1].
The individual risk does not, however, carry any information about the number of people affected in the case of a fire. This aspect is addressed by the so-called societal risk. The societal risk is a measure of risk to a group of people. It is most commonly expressed with respect to the frequency distribution of multiple casualty events. The notion of risk in a societal context is expressed as the relation between frequency and the number of people suffering from a specified level of harm as a result of implementation of specified threats. The societal risk may be modeled by the frequency of exceedance curve of the number of deaths, also called the FN curve due to specific threats. Thanks to A-EVAC multi-agent microscopic simulator, it is possible to calculate the FED exposure for each of the evacuees and then rank the severity of the consequences per the number of people affected. This finally results in FN risk curves.

**Deterministic Models**

The current fire model in Aamks is CFAST version 7.5.1, which provides the fire environment parameters required for the calculation of toxic and thermal FED, as well as movement speed reduction. OZONE is applied for calculating the thermal response of steel construction and its consequences for humans. In practical terms, OZONE calculates whether the critical temperature was reached and the time when this temperature was reached.

A-EVAC handles the collision avoidance based on the velocity time-to-collision approaches and linear programming [7]. The wayfinding algorithm is based on the navmesh approach~\cite{navmesh}. For each position of the agent in each step of the simulations, A-EVAC enquires the created data structure for fire parameters and alters agents’ states (FEDs, speed) respectively and behavior correspondingly. When there is smoke on the evacuation route, the agents try to find an alternative route free of smoke. The behavior related to smoke depends on the agent type: conservative, active, herding and followers as defined in [8]. The detailed description of A-EVAC can be found in [5].

**Model Parameters**

The simulation process starts with the definition of a model of the building where the fire and evacuation take place. The model reflects the compartmentalization and other type of obstacles that can be present inside a building, as well as openings, deployment of safety measures (fire detectors, sprinklers) and others. These parameters are created using special drawing tools.

The model does not change during the simulation process (at least for a given candidate design), hence it can be considered as a set of a fixed set of parameters defining input. This set is then expanded by other invariants related to the physical properties of the building obstacles, environmental parameters (initial indoor temperature, humidity, and others), and physical parameters of safety measures, such as sprinklers spray density and ventilation flow. The number of parameters as well as their type depends on the problem being addressed, building type and other factors.

The second set of input parameters is uncertain or variable and are drawn from the Monte Carlo sampler. The parameters that are sampled include, but are not limited to: a room of fire origin, heat release rate per unit area (HRRPUA), soot yield, CO yield, locations of people in the building during the pre-evacuation stage, door positions, and the operation of a safety system. The
parameters of the probability distributions are mostly based on standards such as BSI 9999:2008 and PD7974-6:2019 or the many scientific records.

The third type of parameter comprises dependent variables. These variables are related to the fixed values or those drawn from the distributions. The heat release rate (HRR) may serve as an example of the dependent variable. The HRR is defined as a function of a drawn sample of HRRPUA and the fire area that depends on the room of the fire origin. An effect the peak HRR is defined as the product of the HRRPUA and the area of the room of the fire origin.

**Availability and Collaboration**

The Aamks software is open source, available at http://github.com/aamks. There is also a demo version available at the project webpage https://aamks.szach.in. The demo version allows preparing a project for simulation, but does not allow launch computation. There are also a number of videos available on the project webpage that present the use of Aamks in the IMO test, compared to other software or just presenting various aspects of software development.

We are open to cooperating both with programmers, fire safety engineers, as well as beta testers. We are particularly expecting assistance in the scope of human behavior in smoke with relation to zone fire modeling, as well as model validation, i.e. the validity of output risks.

**Case Study**

As a case study, we investigate a building housing a concert hall and surrounding corridors and offices. The main hall is 60 m wide, 34 m deep and 6.5 m high. The main entrance to the hall leads through a cloakroom which is 4.16 m wide, 37.4 m deep, and 3.5 m high. The layout of the model is shown in Figure~\ref{layout}. The people in the concert hall were distributed according to the available seats, and in the remaining rooms placed randomly, considering the expected occupation density BSI 9999:2008. The total number of evacuees was 700.

We applied Aamks to calculate individual and societal risks for this building. Thanks to the zone fire model, the velocity-based model for evacuation, and grid computing, the simulations for fire safety concepts can be performed approximately within 30 min on 160 cores @ 2.4 GHz.

**Conclusions and Future Developments**

The primary goal of the discussed case study was to present the main idea of the risk-aware decision making, as well as the easy application of Aamks in the building design process. Therefore, the building layout was rather simple and informative. We also provided the cost of computation of a single scenario for this case study. Taking into account the time required for the computation of a single scenario, one may project the time of computation of the entire project with respect to the number of nodes being available. For example, having one computer with four cores, the expected time of computation of 1000 simulations will be approximately 14 hours. The accuracy for this number of simulations will be of a magnitude of 1e-5. A better accuracy requires more simulations with error reduction rate proportional to the square root of N. However, the increase in the number of simulations also increases the time of computation (with hardware resources unchanged). The calculation of the simulations on grid computing allows for higher scalability and performance. As was presented in the case study only 30 minutes were needed to calculate 1000 simulations.
However, the application of grid computing requires high upfront costs related to outlays to be made in the hardware. Moreover, the setup of a grid or cluster is not always easy and may require support from IT experts. Therefore, we also tested Aamks at Microsoft Azure cloud. We applied one of the Azure solutions called ScaleSet, which allows a dynamic increase in the number of nodes depending on CPU usage of those currently existing in ScaleSet. We set up a project of a 3-storey academic building with 1000 simulations. The computation resulted in a dynamic assignment up to 200 cores and total simulation time of several minutes. The monthly cost of such a solution is at the level of magnitude of €5000. The deployment of Aamks on a commercial cloud has a number of advantages, including among others: a) no necessity of maintenance, b) dynamic scalability, c) dynamic fitting of available resources to current computations needs, d) continuous update of software and hardware, e) lack of upfront costs, f) elimination of downtime, g) no necessity of keeping IT experts for the hardware and software management, and finally h) better energy management and lower CO2 footprint. Nevertheless there are also certain shortcomings related to keeping calculations in the cloud. The most important are costs of calculations in the cloud and the need of becoming familiar with the cloud-specific software. Therefore, the final cost-benefit result depends on the business model of the company, i.e. the number of project, including also their simultaneity, the complexity of the projects, as well as the currently available computer resources and staff.

In the design of our software, we emphasised the ease-of-use and the feasibility aspects. Given to the fact that the majority of input parameters are drawn from probability distributions, the definition of the simulation process is very easy. We are also preparing our own editor for drawing, because we have found that AutoCAD has proven to be too difficult for a considerable part of the users. Therefore, at the moment we are convinced that our software is crafted for engineering purposes. Moreover, the development of the software as a web application releases the users from problems connected with installation and configuration. All the user needs to do is create an account and then is free to use the application. Moreover, several minutes of calculation time per projects on grid or cloud computing may allow the presumption that the tool can be used in the day-to-day process of building design, in which various fire safety concepts can be considered regarding the safety level.

We have also provided a brief outline of how the calculated risk can be further ranked and reported to parties involved in the project design. In the case study, we have adopted the SFPE risk-ranking matrix and PD 7974-7 standard. We also mentioned a more advanced method of risk-informed decision making.

References


Smoke Control for High Rise Buildings

By: Giovanni Cosma, Jensen Hughes S.r.l, Italy. Luciano Nigro, Jensen Hughes S.r.l, Italy

Introduction

Staircases usually cover a key role within a building as they create a connection among several floors interlinking different spaces and occupants which can be used on a daily basis. In the event of an emergency, such as the outbreak of a fire, the staircase acquires a more important role since there’s the need for the occupants to leave the building safely.

It is therefore important to design new buildings in such way that stairwell protection becomes a primary strategy with the intent to provide acceptable and tenable conditions long enough for occupants to evacuate in the event of an emergency. At the same time, staircase protection becomes fundamental, along with other measures, to allow firefighters to safely enter the building and establish a line of a successful firefighting operation.

Designers, architects, and engineers should therefore understand the fundamental role of the staircase in the event of an emergency.

In residential buildings, hotels, or hospital, the escape times might be prolonged (sleeping occupants or with low levels of physical and/or mental abilities) and thus it is essential that escape routes must be kept available and smoke-free for an extended period of time [1]. A combination of passive and active means, such as fire walls, fire doors, and smoke control systems can be the key elements to protect the vertical escape routes.

For many decades, fire incident reports showed us that fires in flats rarely spread beyond the flat on fire [2], [3]. However, it has been proved that smoke may enter into corridors when the residents leave the flat on fire, or firefighters enter the flat to extinguish the fire. That’s one of the reasons why “stay put” strategies were developed. When a “stay put” strategy is adopted, the risk of being affected by smoke reduces, as entering unnecessarily in a smoky corridor may result in being overcome by the toxicants and combustion products of the fire. Staying put also means firefighters can tackle the fire safely and quickly without being delayed by many residents evacuating down the stairways. However, for certain buildings is not always possible to implement a defend-in-place strategy. Hence, maintaining vertical escape free of smoke enables occupants to leave safely, also on a later stage of the fire, whilst enabling firefighters to reach upper levels in case of total
evacuation. As written within the UK national high-rise firefighting guidance [4] “Incident Commanders should understand when a partial or full evacuation strategy might become necessary in a residential building where a “Stay Put” policy is normally in place” meaning that in multi-storey residential building, as circumstances and incidents may change in a dynamic way, there could be a chance where evacuees and fire fighters are using vertical escapes at the same time. It is therefore vital to guarantee tenable conditions for prolonged periods within the vertical escape routes.

To assist means of escape and fire fighter access in high rise buildings it is common practice to provide some form of smoke control to the stairwells or adjacent spaces, which could take the form of mechanical schemes or provisions of natural ventilation [5]. When natural ventilation is used for tall buildings, special attention should be given to the design of the system, as the smoke-driven flow may be affected and altered by loss of buoyancy, piston effect, stack effect, or wind pressures. Natural smoke venting is usually not recommended in fire-fighting shafts serving floors above 30 m above ground level [6].

Several international fire safety standards provide some common guidance on different types of smoke control systems that can be implemented to protect vertical escape paths within high rise buildings. These solutions may include:

**Stair pressurization** – Most building codes require high-rise buildings to be provided with fire rated enclosures for final exit stairs provided with pressurization. Mechanical stair pressurization is the most commonly used approach to meet this requirement for high-rise buildings. For example, the IBC code, which is primarily adopted in the United States of America, specify for tall buildings, which needs to be equipped throughout with an automatic sprinkler system, a mechanical means of smoke control applied by utilizing outside air to pressurize the stair and create a pressure difference between the stair and the occupied space. Similarly, the National Construction Code (NCC) of Australia, which incorporates all minimum necessary requirements for the design and construction of buildings, requires, for fire-isolated stairs serving any storey 25 meters above ground, an automatic stair pressurization system. The primary effect of the pressurization system is to create a minimum air velocity through openings (i.e. doors) to minimize the spread of smoke into the stairs doors. A Similar approach is followed within the UK and Germany [6,] [7].

Egress stairs in high-rise or tall buildings are typically pressurized to prevent smoke leakage through construction cracks and doors opened to provide access. Stair pressurization systems typically require pressures in the range of 25-50 Pa, depending on the applicable local national code.

**Zoned smoke control system** – This type of system divides the building into separate smoke control zones and creates pressure differentials to minimize the smoke spread. Mechanical ventilation is normally provided in the affected areas to exhaust smoke and a positive pressurization system is normally provided for the other contiguous zones. In a high-rise building, zones may consist of entire floors, but sometimes floors are subdivided into multiple zones. An example is the pressure "sandwich" effect in which the fire floor is exhausted, and the floors above and below are pressurized.

**Smoke Clearance** – Post-fire smoke removal systems are intended to facilitate smoke removal after fire-fighting intervention. This can be achieved via operable windows/panels, or via mechanical ventilation capable of providing a prescribed number of air changes per hour. It must be stressed that this type of system is not meant to maintain smoke-free areas.
Atrium smoke control systems – Modern buildings may contain one or more atria or large-volume spaces connecting multiple floors which will require means of smoke venting. This would typically consist of a system designed to establish a stable smoke layer to enable safe escape of the occupants or to dilute the smoke in order to maintain tenable conditions. Mechanical or natural smoke exhaust systems will extract smoke from the top of the atrium with low-level, low velocity make-up air at the bottom of the atrium for a specified time period. Some international building codes allow a combination of all the above smoke ventilation systems (de-pressurization, clearance or temperature control systems) to be installed within such big volumes.

There is agreement that properly implemented stairwell protection systems can provide tenable conditions for evacuating occupants in tall buildings. A variety of different methods are currently in use worldwide ranging from corridors depressurization systems to depressurization of entire smoke zones. As these systems are now being fine-tuned and improved over the years, in the same manner as sprinkler systems or building energy systems have, there is very little agreement and different opinions as to which method is to be used for specific building types. It is therefore down to the fire safety engineer to analyse and draw the conclusions, in coordination with all the stakeholders and AHJs, how to design a system aimed to limit smoke movement to the fire origin zone and guarantee a safe escape of the occupants.

The increasing building heights combined with reduced number of vertical escape routes, are nowadays creating new challenges for fire safety engineers. A smoke control system, if properly designed, reduces the migration of smoke allowing occupants to safely exit the building, even on a later stage of the fire. In the event of a fire, the number of stairwells within a building, if unprotected, might become an irrelevant number, as smoke-logged escape routes will become not usable, causing delays on the required occupants escape time and increasing the efforts that the attending fire brigade needs to put in place.

References