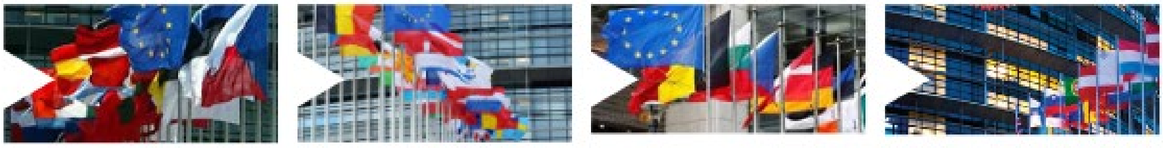
SFPE EUROPE

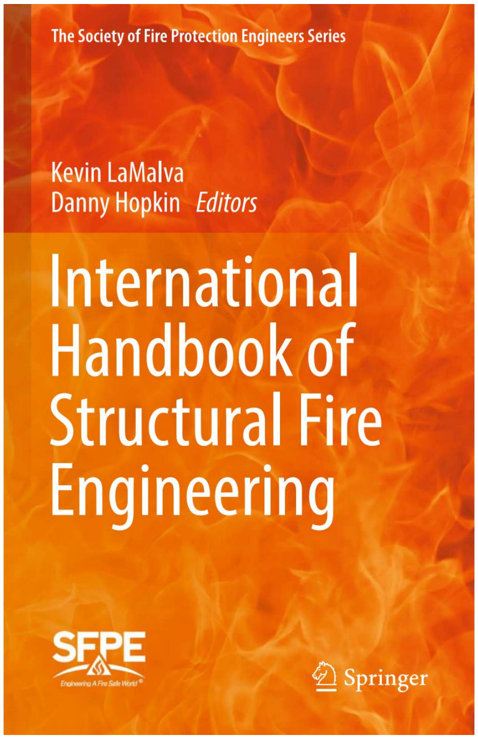


Q3 2021 ISSUE 23 AN OFFICIAL PUBLICATION OF SFPE

SFPE Welcomes New Handbook on Structural Fire Engineering

By: Kevin LaMalva, P.E., Warringtonfire, USA
Danny Hopkin, Eng.D., OFR Consultants, UK

This article introduces the newest publication in the SFPE Series: the first-of-its-kind *International Handbook of Structural Fire Engineering* due out October 2021 [1].



The Society of Fire Protection Engineers Series

Kevin LaMalva
Danny Hopkin *Editors*

International Handbook of Structural Fire Engineering

SFPE

Springer

Figure 1. Handbook Cover

Handbook Subject Matter: *Fire as a Structural Load*

Structural fire engineering is the explicit design of structural systems to adequately endure thermal load effects from structural design fires based on specific performance objectives [2].

Traditionally, structural fire protection is prescribed for structures after they have been designed for other demands, serviceability conditions and hazards, such as earthquakes and hurricanes. Consequently, the vulnerability of buildings to structural collapse from uncontrolled fire varies from building to building and is subject to coincidental structural engineering design decisions made for other demands and hazards.

In response to new and rapidly evolving building construction trends, designers have increasingly sought an alternative to the traditional approach for structural fire protection [3]. Encouragingly, structural fire engineering is establishing itself around the world as a distinct engineering discipline which can fill this void. Structural fire engineering lies at the interface between structural engineering and fire protection engineering, or simply put, structural engineering with fire as a load case. Irrespective of whether it is a discipline it is own right, or subset of another, the process and outcomes are the same irrespective of the region/jurisdiction as follows:

- Definition of required performance objectives.
- Identification and description of structural design fires.
- Expression of these fire exposures as a thermal boundary condition to structural elements.
- Development of temperature within / through structural elements.
- Characterization of material degradation and fire effects (e.g., restrained thermal expansion [4]) due to elevated temperatures.
- Structural system analysis considering material degradation and fire effects.

Structural fire engineering is based on the application of engineering principles and physics-based modeling in lieu of traditional prescriptive rules. This method requires a dramatically higher level of engineering rigor as compared to the traditional approach but can provide many worthwhile benefits. Notably, modest structural upgrades identified in the process can dramatically increase the level of intrinsic structural fire safety even if less fireproofing is applied [5]. At the same time, such measures can significantly improve/enhance project economics, carbon footprint, aesthetics, quality control, site conditions, and life-cycle maintenance [6]. For some types of buildings, e.g., uncommon situations, the application of structural fire engineering may be the only means of satisfactorily demonstrating that an adequate level of safety is achieved [7].

<u>Handbook Utility</u>: ***Global Reach***

The Handbook is intended to provide readers from any region/jurisdiction with an understanding of structural performance in the event of uncontrolled fire. It has been written to mirror the anticipated workflow of structural (fire) engineering consultancies by encouraging consideration of project goals, the likely fires that might develop, the manifestation and estimation of thermal boundary conditions and structural element temperatures, and material and element response to heating. Separate chapters are provided in support of specific considerations, namely those interested in reliability-based analysis of structures in the event of fire, advanced calculation methods for fire exposed structures and the inspection/reinstatement of fire damaged structures.

Fire protection engineers engaging outside the bounds of the traditional approach must be educated in the basics of structural fire engineering, and this Handbook is meant to cultivate such understanding in a convenient and unified media. The Handbook is primarily written for practicing consulting engineers. However, it is foreseen that the Handbook can be a useful resource for students of fire and/or structural engineering who wish to develop a deeper understanding of structural performance in the event of fire, as well as building authorities to assist with review of such alternative designs.

Handbook Contents: *Unifying our Knowledge Database*

The development of the Handbook over the past three years united the best structural fire engineering practitioners and researchers across the world to provide comprehensive guidance for practicing structural fire engineering. Accordingly, the Handbook unifies a significant volume of material on the topic of structural fire engineering. Indeed, the Handbook is a true reflection of how far structural fire engineering has come internationally, as this discipline now has a dedicated Handbook.

The Handbook contains the chapters with authorship as follows:

- Chapter 1: Foreword & Introduction – K. LaMalva & D. Hopkin
- Chapter 2: The Fire Resistive Principle – K. LaMalva, J. Gales, A. Abu & L. Bisby
- Chapter 3: Keys to Successful Design – M. Feeney, K. LaMalva & S. Quiel
- Chapter 4: Design Fires and Actions – D. Hopkin, R. Van Coile, C. Hopkin, K. LaMalva, M. Spearpoint & C. Wade
- Chapter 5: Heat Transfer to Structural Elements – K. LaMalva, C. Maluk, A. Jeffers & A. Jowsey
- Chapter 6: Concrete Structures – T. Gernay, V. Kodur, M. Naser, R. Imani & L. Bisby
- Chapter 7: Steel and Composite Structures – A. Abu, R. Shi, M. Jafarian, K. LaMalva & D. Hopkin
- Chapter 8: Timber Structures – D. Brandon, D. Hopkin, R. Emberley & C. Wade
- Chapter 9: Uncertainty in Structural Fire Design – R. Van Coile, N. Elhami-Khorasani, D. Lange & D. Hopkin
- Chapter 10: Advanced Analysis – T. Gernay & P. Kotsovinos
- Chapter 11: Reinstatement of Fire Damaged Structures – T. Lennon & O. Lalu

Handbook Impact: *Promotion of Intrinsically Fire Safe and Rationally Optimized Structures*

All the pieces are already in place to support structural fire engineering practice across the world. As described in the Handbook, industry consensus documents are available that complete the suite of analyses: fire intensity, thermal response, and structural response. Additionally, the Handbook provides further commentary and guidance on key topics within this discipline. At this point in time, the proliferation of structural fire engineering across the world is a matter of improving individual competence of design teams, improving awareness that alternative solutions exist (when they are needed and when they can add value) and ensuring clients / developers understand the benefits that alternative approaches can bring. Such proliferation will lead to more intrinsically safe structures to fire and provide many opportunities for structural and fire protection engineers to not only serve as integral participants in the design of structural fire protection, but also to add profound value to projects in many cases. Also, this emergence will change the way that project stakeholders view the optimization of a structure. It is envisaged that the Handbook will support this proliferation.

References

[1] LaMalva, K.; Hopkin, D. (2021) International Handbook of Structural Fire Engineering, Society of Fire Protection Engineers (SFPE) Series, 2021, DOI 10.1007/978-3-030-77123-2, ISBN 978-3-030-77122-5

[2] SFPE Recommended Minimum Technical Core Competencies for the Practice of Fire Protection Engineering (2018), Society of Fire Protection Engineers, Bethesda, Maryland

[3] Ellis, A. (2019) "Unleashing the Profession: How Performance-Based Design Will Shape Our Future," STRUCTURE Magazine

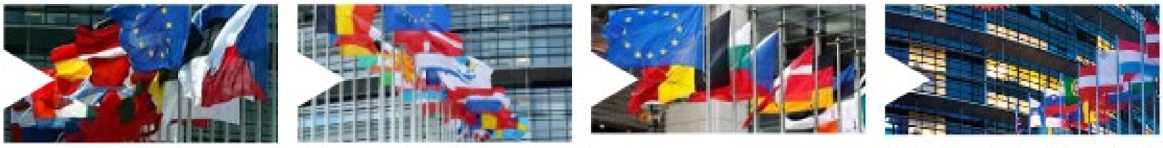
[4] LaMalva, K.; Gernay, T.; Bisby, L.; Torero, J.; Solomon, R.; Gales, J.; Hantouche, E.; Morovat, A.; Jones, C. (2020) 'Rectification of Restrained vs. Unrestrained,' Fire & Materials Journal, Vol. 44, No. 1

[5] ASCE/SEI Design Guide (Performance-Based Structural Fire Design: Exemplar Designs of Four Regionally Diverse Buildings using ASCE 7-16, Appendix E), American Society of Civil Engineers: Structural Engineering Institute and Charles Pankow Foundation, 2020 < https://ascelibrary.org/doi/book/10.1061/9780784482698 >

[6] Post, N. "Structural Fire Engineering Can Improve Building Safety, Schedule," Engineering News Record (ENR), October 2020

[7] P. Wilkinson, D. Hopkin, and B. McColl, 'Chapter 12: Fire Resistance, Structural Robustness in Fire and Fire Spread', in CIBSE Guide E: Fire Safety Engineering, Fourth., Suffolk: The Lavenham Press, 2019.

SFPE EUROPE



Q3 2021 ISSUE 23

AN OFFICIAL PUBLICATION OF SFPE

Performance Based Fire Safety Design: Risk Perceptions and Communication

By: Armin Wolski, Reax Engineering, USA

Fire safety design, be it in a performance or a prescriptive regulatory environment, is effectively an exercise in risk management intended to achieve an acceptable level of risk of fire. The acceptable level of risk would normally be set directly or indirectly by regulation; however, whether any risk is deemed acceptable is more complicated issue. This is made clear in *Acceptable Risk*[1], where Fischhoff and his co-authors explain that by simply targeting numerical acceptable levels of risk is not the key to any successful regulation. Alternatively, they argue that a successful regulation is one that addresses the many facets of the risk, resolving questions such as: Is the regulation practical? Is it logical? Is it compatible with the existing institutions? Is it politically acceptable? For more on these and how they apply to performance-based fire safety, see LINK.

Almost twenty years after the publication of *Acceptable Risk*, Fischhoff revisited such regulatory challenges in his paper *Risk Perception and Communication Unplugged: Twenty Years of Process*.[2] He proposes that the struggles in developing and promulgating successful regulation are universal and adds that too few recognize this "universality." He offers the reasons:

"Although learning from the experience of others is appealing…, it may be difficult. One possible obstacle is being too isolated to realize that others have faced the same tasks. A second is being too headstrong to admit that help is needed. A third is not having a chance to observe others' learning process. As a result, newcomers may be condemned to repeat it."

Analogous to the seven criteria presented in *Acceptable Risk*, Fischhoff's new paper identifies common developmental stages associated with risk management and regulations.

These stages eerily echo many performance-based fire safety design (PBD) implementation challenges, at least in the United States. As fire engineers work worldwide to gain recognition and validation of their discipline, they would be wise to heed where they stand among these stages. Based in large part on the author's practical experience and observations, with insightful excerpts from Fischhoff's paper, these universal stages are discussed in light of the current state of PBD in the United States.

Stage 1. All we have to do is get the numbers right.

"There is concern that the data, tools, and methods are lacking."

Before the first 1996 International Conference on Performance-based Codes and Fire Safety Design Methods[3], and thanks to contributions from engineers and scientists world-wide, several PBD tools, numerous worthwhile data sets had been developed for those practicing PBD. *The National Fire Protection Association (NFPA)* offered[45] risk-based approaches, and in 1988, the SFPE published the first edition of SFPE Handbook[6] with tools and data useful for PBD.

Thanks to researchers worldwide, the numbers are getting "more right" every year. The sixth edition of the the SFPE Handbook is expected to be published sometime in 2022. With the advent of faster and cheaper computers and the development of more user-friendly tools, computational fluid dynamic modeling has almost become the norm in PBD, delivering improved accuracy. But it is unlikely we are finished with this stage. [7] Better fire and smoke spread model input data (design fire assumptions) and human behavior models (a highly stochastic phenomenon) are needed. Although we have 30+ years of available performance based fire safety data and tools to draw from, this developmental stage may never be truly seen to completion.

Stage 2. All we have to do is tell them the numbers

"When risk managers discover that they have not been trusted…a natural response is to hand over the numbers. How good a story those numbers tell depends on how well the first stage has been mastered."

The 2nd stage suggests that PBD be transparent. The SFPE has made efforts to push transparency through publications on PBD. Among them is the SFPE Code Official's Guide to Performance-Based Design Review[8] (Guide). Per the Guide, early engagement with the authorities having jurisdiction (AHJ) or their representatives is highly recommended. As part of the engagement, it is important the "numbers", assumptions and inputs be shared with the AHJ. Some important numbers in many PBDs include heat release rate, soot yield, heat of combustion, visibility limits, and occupant characteristics. Many of us have worked through this stage and understood that a basis of design report is a good vehicle to provide such information. Such a report can tell the story, provide the key numbers, and ideally be shared with AHJ before formal start of any analysis.

Stage 3. All we have to do is explain what we mean by the numbers

"When the numbers do not speak for themselves, explaining them is an obvious next step. Those who attempt such… face significant… problems, including a largely unprepared audience. Clearly communicating any number is a complicated task."

At least in the U.S., building fire safety design, particularly PBD, is not performed in a vacuum. Often a peer reviewer (a prepared audience) and an AHJ (sometimes a less prepared audience) are involved. For this reason, clarity in communication of the numbers important. For example, giving simple "single point" numerical results may not always communicate the problem or the solution very well. For guidance in reporting results in a PBD, the Guide recommends a way to put results in context:

"The design report describes the final design, documents the engineering analysis used to determine the final design, and identifies the bounding conditions for the analysis."

Another way of reading the phrase: "*identifies bounding conditions,*" is: "*at what point, does the design fail?"*[9] This is recognized in *NFPA 101 The Life Safety Code*[10] where as part of its PBD process, it has formalized eight potential fire scenarios to consider. The eighth scenario requires that one or more fire safety design features fail. In case single point results are inadequate, this exercise is one way to provide reviewers a much better appreciation of what the numbers, the results, mean.

Stage 4. All we have to do is show them that they've accepted similar risks in the past

"risk comparisons, in which an unfamiliar risk is contrasted with a more common one, individuals…use their response to the familiar situation as a guide…in the new one."

In the U.S., the most popular method used to justify PBD is based on the principle of equivalency to the prescriptive code.[11] The majority of such PBDs are efforts in showing that the design equals the intent of a prescriptive code section. For example, if more exit width is provided than required prescriptively, yet the maximum allowed exit travel distance to an exit is exceeded, a PBD can show that the flow of occupants through the exit width is just as efficient, the occupants can exit equally as fast and therefore the design might be equal that of the prescriptive code. In this case, the fire engineer shows the AHJ that "since they have accepted this risk in the past, they should do so now.[a]" This approach, embraced in many parts of the US, has been a great value for PBD, yet may not work 100% of the time, which leads us to Stage 5.

Stage 5. All we have to do is show them that it's a good deal for them

"People need information about both the risks and the benefits of any activity that might affect them…. Explicitly showing the cumulative benefits of a protective measure may enhance its attractiveness."

---

[a] Outside the United States, other examples of this step are evident. The early Australian efforts in performance-based codes suggest comparing the risk consequences in terms of equivalent risk to life (ERL) or Fire Cost Expectation (FCE) to a deemed to satisfy or prescriptive design.

Benefits of PBD are often clear to the stakeholders on the design team. However, to the AHJ, PBD be perceived as adding uncertainty, thereby increasing the real or perceived risk.

It is for this reason that often, in the United States, any PBD needs to consider a level of safety that equals *or exceeds* that level of safety intended by the prescriptive code. In the previous example, a building's prescriptive exit travel distance exceeds the code allowed maximum, but because the egress widths provided are in excess of the prescriptive requirements, equivalent egress times are predicted. However, this "equality" may be inadequate to address the AHJ's concerns and uncertainties of the predictions. Often, this has meant that one or more additional safety features may be necessary in order to truly show it is "a good deal for the AHJ." This concept of providing "more" than equivalent is not completely irrational. To the AHJ, the process can allay concerns regarding the seen and unforeseen uncertainties and accommodate their perceptions of risk.

Stage 6. All we have to do is treat them nice

*"Getting the content of a communication right requires a significant analytical and empirical effort…(*the AHJ*) may ask how trustworthy the communication and communicator seem to be. The ignorant smiles of PR types are a good tool for digging oneself into a hole".*

Much is written about soft skills: the skills of communication and empathy versus the counterpart set of hard skills or technical proficiency. But some believe that the weaknesses in PBD lies not only in the technical realm but also in the realm of trust: in the trust of the tools, in the trust of the analyst or fire engineer, or in the trust of the construction and maintenance processes.

In *A Risk-Informed Performance-Based Approach to Building Regulation,*[12] Meacham writes:

"….for regulators and enforcement officials, <u>performance-based (</u><u>fire safety design</u>*<u>) approaches are often met with skepticism and concern</u>, as the desired performance is not always well defined and agreed."*

Where the number of fire engineers practicing PBD are limited, and where the number of professionals in AHJ roles are more limited, respect and trust are required. Fortunately, the SFPE provides support for these stakeholders with regional, local SFPE Chapters. The SFPE Chapters host regular meetings which provide opportunities for practitioners and the AHJ to meet, present and discuss challenges in a low-pressure environment. At the meetings these would-be partners can exchange ideas and opinions outside of the context of a project, where trust can be gained.

Stage 7. All we have to do is make them partners

"lay people often…master technical material when sufficiently motivated. Unfortunately…the motivation often comes from a feeling of having been wronged. If passions become inflamed…then all sides will be tempted to focus on data supporting their prejudices.

There are still many jurisdictions that might not include enough engineers or design professionals on staff qualified to review PBDs. This should not absolve the design engineer from engaging with the AHJ with an aim to create a partnership. Early communication, can lead to partnership. Partnership can lead to resolving PBD challenges together, as players on the same team rather than opposing players on different teams.

A key tenet of the *SFPE Code Official's Guide to Performance-Based Design Review Guide* is that the process needs to involve all the stakeholders of the design, including the AHJ:

"The owner, designer, and code official should work together as a team with a common goal of a successful project"

Whenever this author finds AHJs who can contribute like team members, PBDs are more welcome and their process of review and approval more easily managed.

Stage 8. All we have to do is all of the above

*"Risk communication has to be taken seriously. A**…**network of…respectful relationships may offer the best hope of reaching agreements.*

The developmental stages of successful risk management, successful fire regulations, and successful PBDs require above all, fact-based evidence: data, methods, tools and results. But, implementation and promulgation of PBD will suffer if wide spread communication is not also valued. There is need for communication in many different arenas of the design and construction industry. PBD succeeds when the regulatory umbrella under which it operates is developed and executed in concert with all of its partners, from architects to manufacturers to authorities having jurisdiction. The *1998 Pacific Rim Conference and Second International Conference on Performance-Based Codes and Fire Safety Design Methods* brought fire engineers, fire scientists together with AHJs, architects, and code development professionals. It was an early step in the right direction for bringing large contingents of key partners together. For future fire engineering conferences, symposia, and similar meetings we should make it a priority to bring more of our partners together.

References

---

[1] Fischhoff, B., Slovic, P., Derby, S.L., Keeney, R.L., *Acceptable Risk*, Cambridge: Cambridge University Press, 1981.

[2] Fischhoff, B., *Risk Perception and Communication Unplugged: Twenty Years of Process*. Risk Analysis, Volume 15, No. 2, 1995.

[3] *Proceedings of the First International Conference on Performance-based Codes and Fire Safety Design Methods*, *Ottawa, Canada,* Society of Fire Protection Engineers, 1996.

[4] *NFPA 550 Guide to the Fire Safety Concepts Tree,* National Fire Protection Association, 1986.

[5] *NFPA 101A, Guide on Alternative Approaches to Life Safety***,** National Fire Protection Association, 1988.

---

[6] *SFPE Handbook of Fire Protection Engineering,* Society of Fire Protection Engineers and National Fire Protection Association, 1988.

[7] Hurley, M. and Rosenbaum, E., *Performance Based Fire Safety Design*, Society of Fire Protection Engineers, 2015.

[8] *SFPE Code Official's Guide to Performance-Based Design Review,* Society of Fire Protection Engineers, 2004.

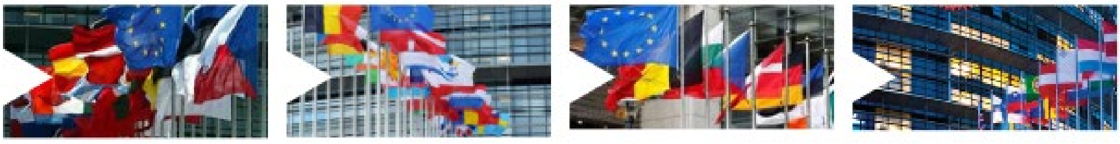
[9] Personal communications per a conversation with Joe McElvaney, retired fire protection engineer (AHJ) from the City of Phoenix Arizona,

[10] *NFPA 101 Life Safety Code, Chapter 5 Performance Based Option,* National Fire Protection Association, 2018.

[11] *International Building Code, 2018*, *Section 104.11*, International Code Council, 2018.

[12] Meacham, B., *A Risk-Informed Performance-Based Approach to Building Regulation,* Journal of Risk Research 13(7), September 2010.

SFPE EUROPE



Q3 2021 ISSUE 23

AN OFFICIAL PUBLICATION OF SFPE

Wind Turbines: Towering Inferno or False Alarm?

By: Guillermo Rein, Eleanor Westhead and Edmund Ang
Department of Mechanical Engineering, Imperial College London, UK

The world is shifting to renewable energy and wind is one of its leaders. Wind turbines now account for over one third of the world's renewable power capacity. This article explores the impact of fire and the role of fire protection engineering on the wind industry. Fire is not a trivial hazard for the wind industry and it remains understudied.

1. Wind as leading renewable energy

The world is shifting to renewable energy because of the challenges of climate change and the finite supply for fossil energy generation. In this context, wind turbines are a leading energy generation type. A recent study [1] estimates that wind energy now accounts for one third of the global renewable power capacity. As shown in Figure 1, wind energy grew slowly at the beginning of the century, but in the last decade capacity has increased at an exponential rate. The future is bright, and wind attracts over one fifth of the world's financial investments in renewable energy, amounting to $6 billion in 2018 [1].

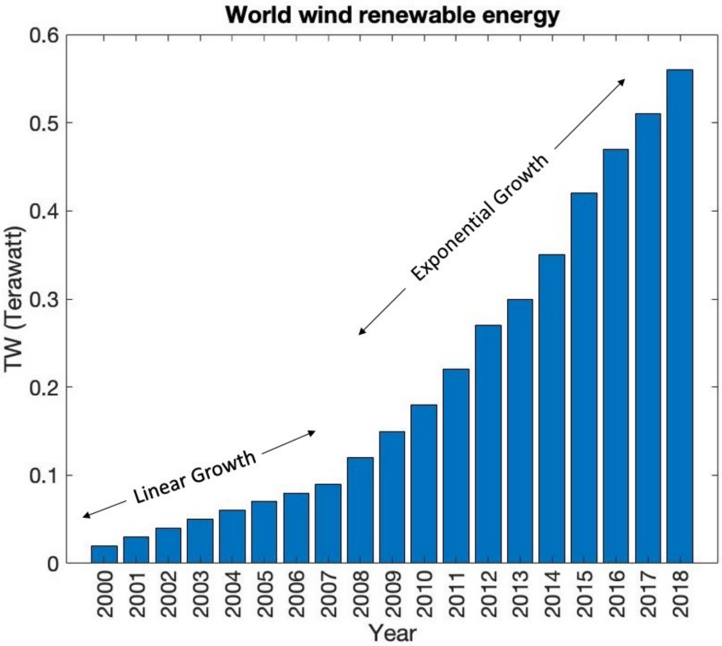


Figure 1. Growth of the global power capacity of wind energy since the year 2000. At the beginning, growth was linear but now it has taken off and wind energy capacity increases exponentially. Sources of data IRENA, BWE and GWEC.

To ensure that wind energy generation can remain competitive and keep pace with increasing demands in efficiency, there is a continuing trend on increasing the height of the turbines and the length of the blades. The historical evolution of turbine size is shown in Figure 2, whose average growth rate in height is 4 m per year. In 2015, turbines already could be as tall as 140 m, with blades up to 80 m long. In the foreseeable future, turbine size is expected to continue growing.

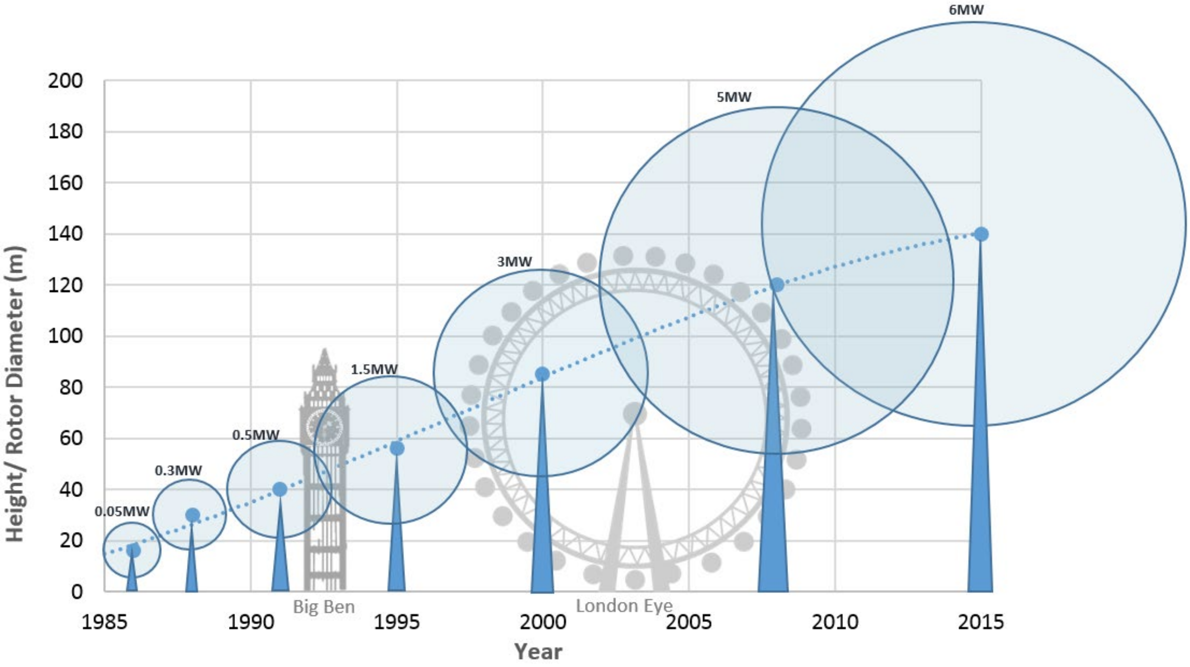


Figure 2: A London centric illustration of the growth of turbine size since 1985. The average growth rate in height is 4 m per year. Background compares sizes to the Elizabeth Tower (aka Big Ben) and the London Eye. Figure inspired after Prof Henry Seifert.

The reasons driving the increase in turbine size are power and return on investment, because every small gain in power capacity represents millions of dollars in revenue over the lifetime of a turbine. By increasing the size of the blades, the efficiency improves because the turbine captures per revolution more wind movement to convert into the torque driving the electric generator. Also, by increasing the height of the turbine, the blades are placed higher up where wind flows faster because there is less effect of ground friction and less flow disturbances by surrounding terrain, forest or structures.

Wind energy generation is a relatively new commercially viable technology, still maturing fast, which was made recently profitable thus attracting more investors. Therefore, future investments could be sensitive to costs and uncertainties. Fire accidents are a source of both costs and uncertainties. Each wind turbine costs in excess of \$2 million and generates an estimated income of more than \$0.5 m per year. Any loss or downtime of these valuable assets makes the industry less viable and productive. Moreover, the trend to install ever larger turbine means the cost per fire trends to increase as well. Also, any one wind turbine fire is very visible to neighbors and the media (both mass media and social media), and also the smoke emissions can cast a shadow over the industry’s green credentials.

2. What are the key fire challenges posed on wind turbines?

The following are three case studies of actual wind turbine fires around the world that illustrate the variability of possible scenarios and the key challenges posed.

Figure 3: The nacelle and blade of this wind turbine in England were burning at height. Photo by Cambridgeshire Fire and Rescue Service, 2018.

In June 2012, a wind turbine in Riverside, California, caught fire due to arching in the generator. According to the incident report by the fire brigade [3], the fire was detected by a resident. Despite the area cleared of vegetations around the base, firebrands (burning debris) from the nacelle fell on vegetation further away and caused a wildfire. The wildfire destroyed 4 km² of forest, burnt power lines and several other turbines. Residents were evacuated, and 100 firefighters attended. This case illustrates the challenge of secondary fires on nearby forest or urban sites. Owing to the significant height of wind turbines, firebrands can travel long distance aided by the wind, creating the need to protect against fire not just the wind farm but also a large area around it. In fact, our review of worldwide fires reported in the media between 2012 to 2016 shows that 12% of the turbine fires cause secondary fires in industrial or forested areas, whereas 73% are contained to the turbine alone and the rest (15%) are unknown containing cases.

In October 2013, a short circuit caused a fire inside the nacelle of a wind turbine in Netherlands [4]. At the time of the fire, four technicians were doing maintenance work inside the nacelle, and two of them were trapped by the flames and smoke. They could only evacuate to the roof of the nacelle where they waited to be rescued but sadly succumbed to the fire. These were the first recorded fire fatalities in a wind turbine. The difficult access to the nacelle housing highlights the issue for technicians performing work in wind turbines which increases the risk to life in case of fire.

In January 2016, an electric arc resulted in a turbine fire in Germany and three technicians were injured with burns and smoke inhalation [5]. Firefighters attended but owing to the height of the turbine, they did not have an adequate mean to suppress it, relegating the response to preventing secondary fires.

The fire self-extinguished after 3.5 h of burning. This case highlights the challenge that the height of a turbine restricts firefighting. Our review of worldwide fires reported in the media between 2012 to 2016 shows that only 10% of the fires were suppressed by the Fire Service, whereas 72% were left to burn out and the rest (18%) were unknown suppression cases. This is a low number of successful suppression cases indeed.

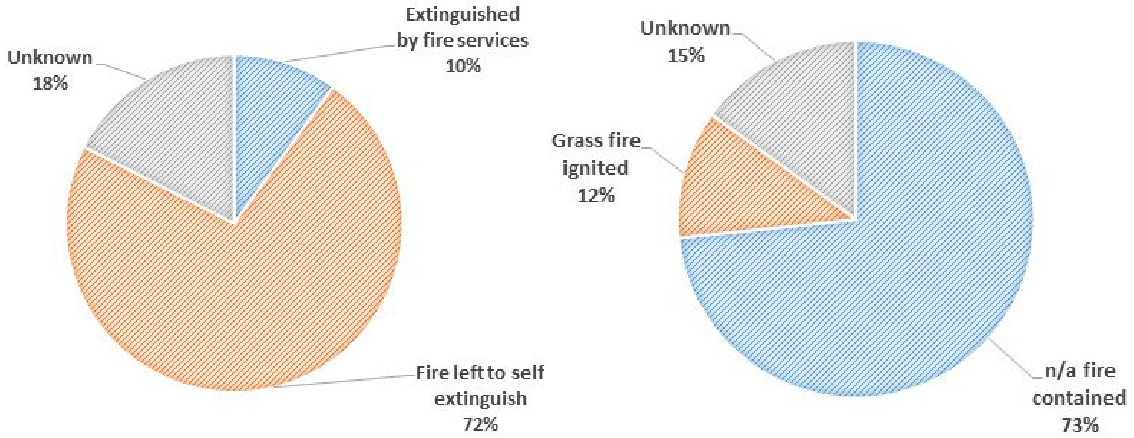


Figure 4. Results from a worldwide media search of turbine fires between 2012 to 2016. 120 fires were found. Left) Role of firefighting suppression. Right) Igniting of secondary fires.

3. How often do wind turbines catch fire?

With an appreciation of the key fire challenges to wind turbine, we turn to the questions: *is fire a cause of concern for the wind industry*? Are the three cases above just sporadic episodes amplified by the dramatic images in the media? How often do wind turbines catch fire?

The data in Figure 5 taken from [2] shows fire is the second leading cause of accidents in wind turbines (15% of the incident), after blade failure (19%). However, blade failures generally do not destroy the entire turbine while 90% of fires lead to total loss of the turbine.

A previous study [2] found 200 turbine fires worldwide from 1995 to 2012, this is 12 fires per year on average. We have extended this search from 2012 to 2016, and we found 120 fires, doubling the rate to 27 fires per year. The number of fire incidents seems to be accelerating. But this is a small number, just 1 fire per 10,000 turbines worldwide, which means the industry is safe by comparison with compared to other energy industries, like oil and gas that globally suffers thousands of fire accidents per year, some with devastating environment impacts. But a pressing question to consider is that in the context of all the challenges faced by the wind industry, is fire an important consideration?

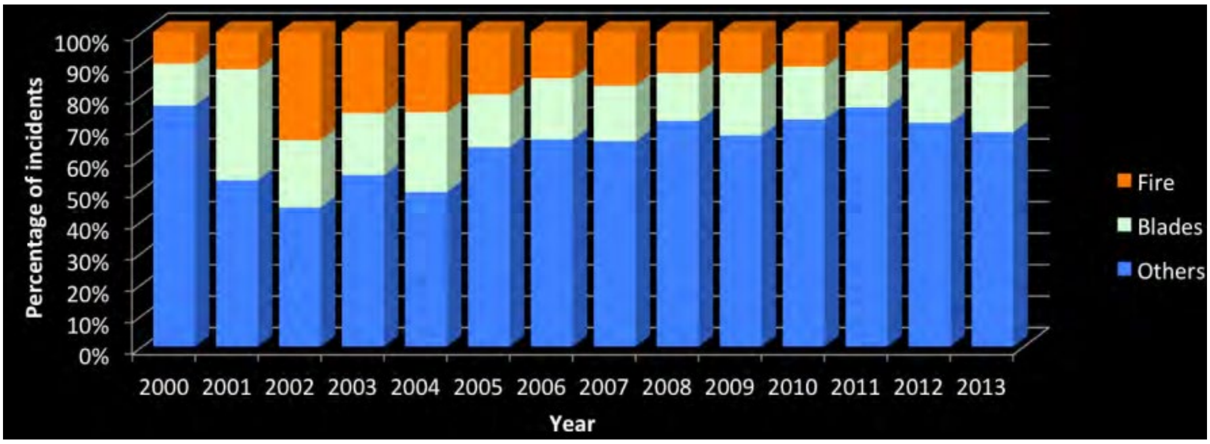


Figure 5. Cause of wind turbine incidents including fires, blade failures and others. Data taken from [2] which source is CWIF.

In trying to answer these questions, we faced a first hurdle in that there is little data publicly available. The best source existing right now is ad-hoc reporting by mainstream media and social media, which brings a bias towards countries with international online journalism like USA, UK and Germany (63% of the fires are reported there), and completely misses Asia which account for 1/3 of installed power. Other databases are Bundesverband WindEnergie, CWIC and Bulldog. CWIF (Caithness Windfarm Information Forum, UK) is the biggest and most accessible database (curated from media reports) but they run a self-confessed anti-wind turbine agenda which can be perceived as a conflict of interest. We have independently confirmed many of the fires reported by CWIF, and therefore we know these fires did occur. Two key databases used in the 2012 landmark study [2] are no longer accessible: AREPA and Bundersverband landschaftsschutz. The question remains: are we just seeing the tip of an iceberg? We know of pro-wind associations who have confirmed they hold large databases on turbine fires, but unfortunately, we have not been granted access to the data despite our requests. Therefore, any analysis is restricted to what is publicly available. This is our best endeavor at this point in time.

4. Anatomy of a wind turbine fire

The three elements of the fire triangle (fuel, air and ignition) are all present inside the turbine nacelle, near each other. Air is plentiful around and inside a turbine, so the focus is on the fuel and the ignition as illustrated in Figure 6.

The fuel consists of various flammable components like oils in the transformer, hydraulic or lubricant. For example, a study [6] of flammability hazards of oils in a turbine nacelle indicates that the transformer oil is the easiest to ignite while lubricating grease is the most difficult. In addition, there are hundreds of meters of cables (a flammable component) for power and communications. Other fuel sources include the insulation for sounds and heat, and the composites of the nacelle housing and the blades.

For the other element of the fire triangle, there are four known ignition sources in nacelles [2] which in order of importance are lightning strike (despite turbines having lightning protection), electrical malfunction (short-circuit or arching), mechanical malfunction (hotspots or motor failure), and hot maintenance work (low safety during maintenance like welding).

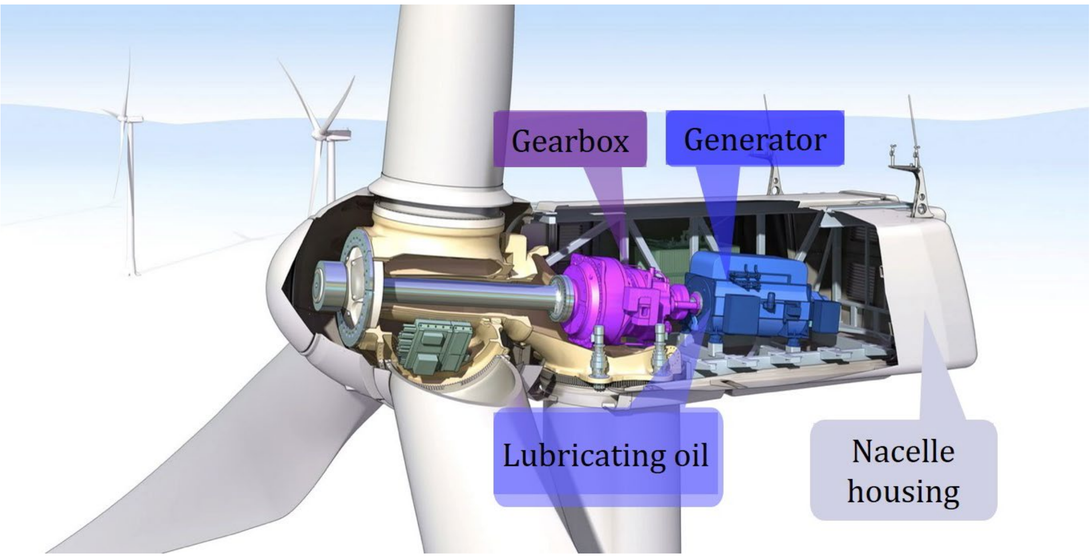


Figure 6. Schematic of a wind turbine highlining its four most important elements in term of fire hazards, based on a similar figure in [2].

5. Solutions? Disrupt the fire triangle and Smart systems

The rough analysis of a wind turbine fire as done above provides a better understanding of the problem. This helps in developing effective solutions. For the complex situation of a wind turbine, we advocate the philosophy of system safety made up of a series of layers of protection including prevention, detection, evacuation, compartmentation and suppression and stability.

For prevention, the risk of a fire can be reduced during the engineering design stage by disrupting the fire triangle and separating ignition sources and fuels. For example, by reducing the failure points, e.g. increase machine maintenance to avoid hotspots due to excessive friction, minimizing cable junctions that could fail electrically, or advancing the use of direct drive turbine which do not require a gear box (no lubrication oil and no hotspots there). The fuel size can be controlled by reducing the presence of flammables, e.g. by replacing mineral oil with synthetic oil, and considering the use of composite materials with low flammability.

The evacuation layer requires a reliable and fast detection to begin with so that technicians are immediately aware of the peril, and egress can be supported by providing additional routes for a quick egress, like foldable ladders or ropes (already existing in some turbine designs) [7]. Compartmentation would require major re-designing for fire and smoke resisting walls separating the major parts of a nacelle (gear box from generator?). The structural stability layer would be to design additional resistance in the nacelle, the blades and the tower to minimize chances of collapse during a fire or shortly after it.

For the suppression layer, water mist systems or gas flooding systems could be considered as a compromise between size and fire suppression efficiency in the close compartment of the nacelle. We appreciate the substantial weight associated with the gas-based suppression system, plus these systems are also very costly and requires a significant space. A localized fire suppression system focused on the most flammable element could also be considered to put out a small fire before it grows to damage the turbine. A localized system is likely to provide a balance between cost, space, weight and effectiveness compared to a full system for the whole of the nacelle interior.

But above all, a systems design approach to fire protection can take advantage of the fact modern wind turbines are already equipped with myriads of smart sensors that monitor its performance in real time. However, none of these sensors are used for fire safety. For example, a good detection layer calls for smart devices that avoid very costly false alarms by combining heat and gas composition signals in multiple points. Or using temperatures sensor to detect overheating ahead of an ignition event.

These sensors can be utilized as a first line of defense whereby if an anomaly is detected, an alert signal can be dispatched, or a shutdown can be initiated. Further when sensors and data collected are paired with a smart algorithm, an automated predictive maintenance monitoring regime can be implemented where the smart system can attempt to predict the potential point of failure and provides an early warning to the operators that a specific wind turbine should be checked.

6. Conclusions

Fire is a cost, an extra liability and a negative public image for wind energy. Fire is the 2nd most frequent incident in wind turbines, and often leads to the total loss of a turbine. Media reports about 1 turbine fire per day worldwide and this is just the tip of iceberg. The true extent of the fire impact on wind energy remains unknown.

Wind turbine fires are an investment risk but also a life safety risk due to the difficult evacuation of technicians, and that the fire cannot be suppressed from the exterior due to their height thus often leading to a total loss of the turbine. Further, a fire creates an additional hazard zone where secondary fires could be possible.

Our experience underlines the fact that wind energy needs to have a complete and open approach to data on fire incidents. The availability of such statistics will enable risk professionals to carry out a probabilistic cost benefit analysis to examine the pros and cons of each option, weighing it against the implementation cost, consequences cost and the level of risks expected. We want to emphasize that engineering solutions exist, but we need to first understand the phenomena, causes and the extent of the challenges.

We hope this work encourages others to pursue this problem, and to make the data available so the fire community can contribute to fire-proof wind turbines, thus better secure this key element in our world’s energy future.

References

1. IRENA, International Renewable Energy Agency. *Renewable energy statistics 2019*. July 2019. Web: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jul/IRENA_Renewable_energy_statistics_2019.pdf

2. S. Uadiale, E. Urban, R. Carvel, D. Lange and G. Rein. *Overview of problems and solutions in fire protection engineering of wind turbines.* Fire Safety Science 11, 983-995, 2014. 10.3801/IAFSS.FSS.11-983

3. CAL FIRE. *Interagency Report of Incident and Dispatch Action Incident 12-CARRU 059775*. June 2012. Web: https://www.eastcountymagazine.org/sites/eastcountymagazine.org/files/2012/July/ViewFire%20report.pdf

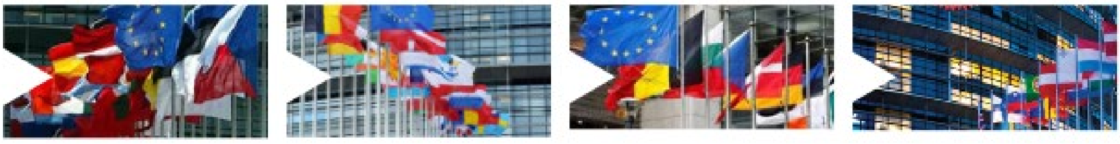
4. NL Times. *Dead in fire wind turbine Ooltgensplaat*. October 2013. Web: https://nltimes.nl/2013/10/30/dead-in-fire-wind-turbine-ooltgensplaat/

5. Daily Mail. *Massive wind turbine catches fire and burns for hours*… August 2016. Web: https://www.dailymail.co.uk/news/article-3762477/Massive-wind-turbine-catches-fire-burns-hours-German-fire-fighters-don-t-ladders-long-tackle-100m-high-blaze.html#ixzz4Ijp9vPvp

6. W. Zhenhua, Y. Fei, G. Rein, J. Juncheng, H. Xuefeng, H. Junhua and S. Wei. *Flammability hazards of typical fuels used in wind turbine nacelle.* Fire and Material Volume 42, Issue 7, 2018. https://doi.org/10.1002/fam.2632

7. B Rengel, E Pastor, D Hermida, E Gomez, L Molinelli, E. Planas, Computational Analysis of Fire Dynamics Inside a Wind Turbine, Fire Technology (2017) 53: 1933. https://doi.org/10.1007/s10694-017-0664-0

SFPE EUROPE



Q3 2021 ISSUE 23

AN OFFICIAL PUBLICATION OF SFPE

Update on a large-scale CLT experimental campaign for commercial enclosures

By: Danny Hopkin, OFR Consultants, UK; Michael Spearpoint, OFR Consultants, UK; Carmen Gorska, Stora Enso, UK; Harald Krenn, KLH, Austria; Tim Sleik, Binderholz, Austria; Gordian Stapf, Henkel Engineered Wood, Switzerland and Wojciech Wegrznski, ITB, Poland.

Introduction

When conceiving of a new office building in the UK, timber is increasingly considered as part of any potential framing solution. This is driven by a combination of embodied carbon, aesthetic and constructability considerations. Commercial premises, such as offices, often have specific user / client demands, with emphasis placed on high floor-to-ceiling heights, long spans between column members and large areas of glazing. For this reason, the UK market is converging upon hybrid construction solutions where timber, in the form of cross-laminated-timber (CLT), is used in concert with other materials, such as steel and concrete (Figure 1).

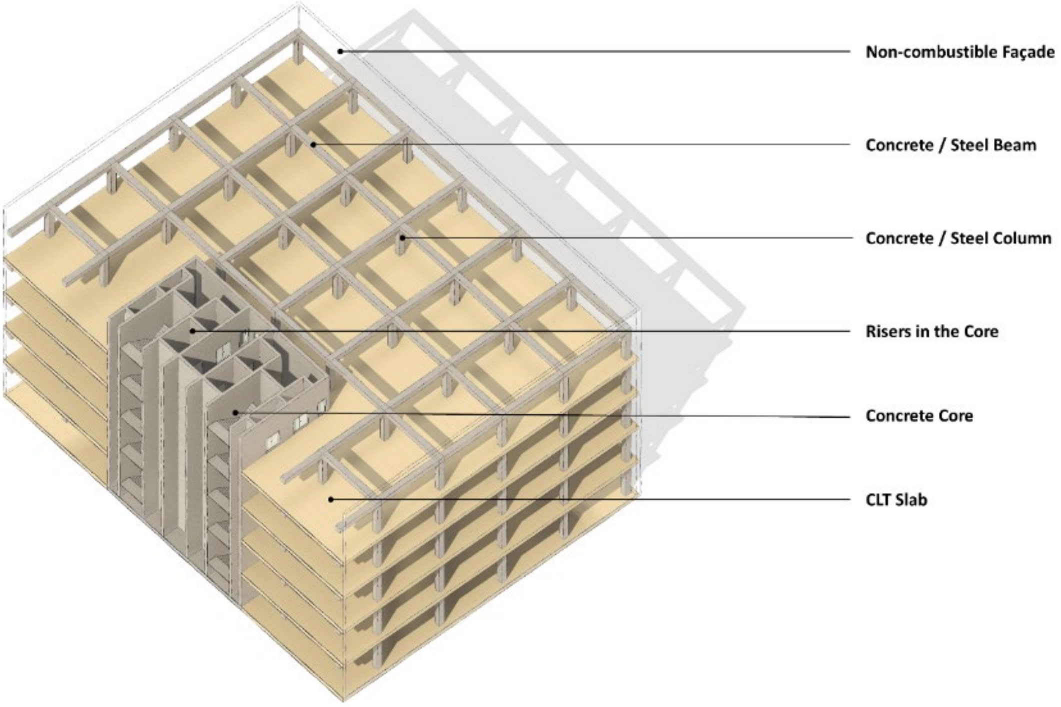


Figure 1. Illustration of a hybrid commercial structure, utilising CLT as floor members.

Recent guidance [1] has been published which has clarified what design evidence should be provided by engineers when demonstrating that an adequate level of safety will be achieved when adopting a combustible structural framing solution. In higher-consequence-of-failure buildings, e.g., medium- to high-rise offices, the structure must be designed in a manner whereby it has a reasonable likelihood of surviving the full duration of a fire [2]. This necessitates that if the structure becomes involved as a source of fuel, it must undergo auto-extinction and remain capable of supporting the applied loads both during and beyond a fire. Allied to this, it is often considered that preventing glue-line integrity failure (GLIF) when adopting CLT is a prerequisite for auto-extinction.

The configuration, scale and fire design of in-demand commercial buildings are, however, increasingly detached from research that has been conducted to date, which has tended to focus on experimentally investigating fire dynamics in combustible residential-type enclosures. An extensive review of current large-scale testing is provided in Ronquillo *et al*. [3]. This focus on residential enclosures has meant little knowledge has been generated for large enclosures, where the combustible elements typically only comprise a single surface, e.g., a CLT floor slab. Therefore, on the one hand, good guidance exists directing designers towards what evidence should be generated, but on the other, little focus has been given to generate knowledge for the types of building increasingly most in demand. To this end, as part of a larger Structural Timber Association (STA) Special Interest Group project on mass timber compartment fire behaviour [4], a series of experiments have been recently undertaken at ITB in Warsaw to support designers in the realisation of mass timber commercial buildings. The emphasis is on those cases where only a combustible ceiling is exposed. This article serves to provide a brief update on the research programme, inclusive of some qualitative and quantitative findings from the experimental campaign. Further publications are intended to follow which will fully and rigorously analyse and report on the studies.

Objectives

The primary objective of the experimental campaign was to address, first and foremost, whether averting GLIF is a prerequisite for auto-extinction for specific configurations representative of current UK commercial premise demands. As a secondary series of objectives, in support of understanding large compartment fire behaviour, the experiments were designed to:

1. Quantify how the ceiling jet characteristics change below a mass timber soffit compared to that of an inert soffit;
2. Quantify to what extent heat fluxes in advance of the fire front (i.e., from the near field region and ceiling jet) altered because of adopting mass timber soffits over inert soffits; and
3. Quantify to what extent external flaming was a realistic proposition for enclosures with mass timber ceilings and large ventilation openings, with emphasis on the heat flux in the spandrel zone.

The enclosure

The experimental enclosure had internal dimensions of c. 4.5 m x 9.5 m x 2.6 m. Three of four elevations were enclosed in blockwork (Figure 2). The ceiling varied between experiments, i.e.:

- Experiment 1: CLT lined with 2 x 15 mm layers of Type F(fire-rated) plasterboard;
- Experiment 2: Exposed CLT using a regular polyurethane (PUR) adhesive (Henkel Loctite HB S); and
- Experiment 3: Exposed CLT using a heat resistant PUR adhesive (Henkel Loctite HB X).

The CLT in experiment 1 and 2 was non-edge-bonded, whilst in experiment 3 it was edge-bonded. The layup was 40-20-40-20-40 mm. The CLT was supported on a rolled-steel frame, suspended from 8 load-cells, and spanned 4.5 m.

The fire exposure

The ceiling was heated using propane gas burners, elevated to sit 1 m below the soffit. The burners were located off-centre (Figure 3), with the aim of inducing a ceiling jet extending to 50% of the ceiling length in experiment 1. The fire's heat release rate (HRR) was controlled via mass flow switches, leading to a HRR that ramped to a maximum of 1,250 kW (achieved over an 8 min period in 250 kW steps). The duration of steady-heating (at 1,250 kW) was chosen to induce GLIF in experiment 2, resulting in a steady-phase duration of 80 min. After this phase, the burners ramped down in 250 kW increments every 5 min, before being turned off. An image during the growth phase of experiment 3 is shown in Figure 4.

Figure 2. Experiment 1 compartment.

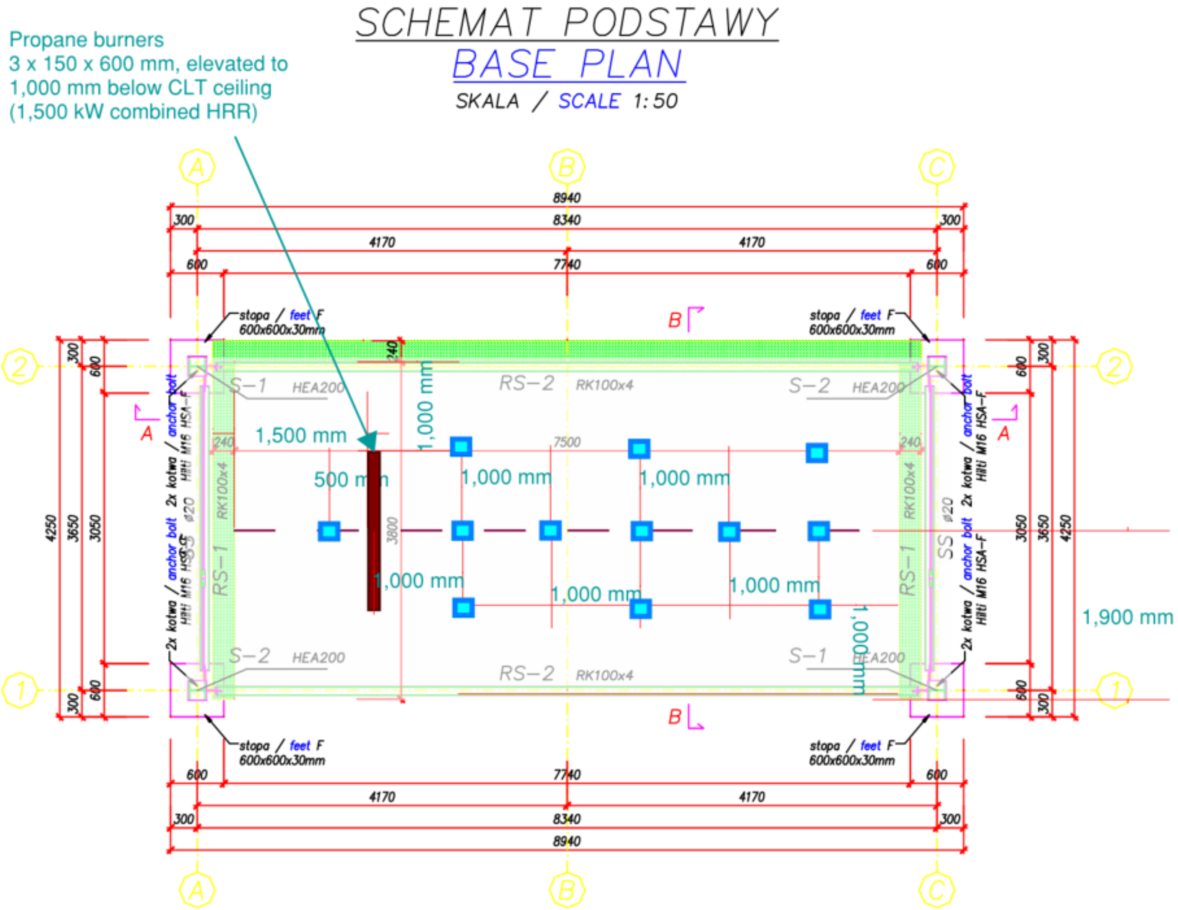


Figure 3. Rig floor plan showing offset propane burners and ceiling arrangement of plate-thermometers.

Figure 4. Flames from burner impacting ceiling in experiment 3.

Measurements

The experiments were extensively instrumented to collect data on:

- The HRR from the burner;
- The HRR from the CLT slabs via load-cells;
- Incident heat flux to the (internal) floor, ceiling and walls;
- Incident heat flux to targets outside of the enclosure;
- Incident heat flux to the façade extension above the openings;
- Gas-phase temperatures throughout the enclosure;
- Solid-phase temperatures within the CLT; and
- Slab deflection at mid-span.

Preliminary observations

Analysis of the data from the experiments remains a work in progress. However, to date, the following observations have been made.

Impact of GLIF on auto-extinction

In both experiment 2 and 3, the exposed CLT underwent auto-extinction, with flaming combustion gradually ceasing from right to left, in the orientation given in Figure 2. In experiment 2, extensive GLIF was observed, with large pieces of lamella falling from the ceiling and continuing to burn on the floor (Figure 5). In experiment 3, GLIF was substantially reduced (Figure 6). Logically, for the specific and simple configuration of an exposed ceiling in an otherwise inert enclosure, avoiding GLIF was not observed to be a prerequisite for auto-extinction. It is important to stress that this is not a general finding, but an artefact of the specific configuration / geometry evaluated.

Figure 5. Extensive GLIF in vicinity of burner in experiment 2.

Figure 6. Limited GLIF above burner in experiment 3.

Combustible ceilings and the ceiling jet

In advance on the experiments, it would logically be postulated that the presence of a combustible soffit would alter the ceiling jet characteristics, both in terms of flame length and heat flux to the ceiling. This is confirmed in Figure 7, where the radiative heat flux to the ceiling is estimated from plate thermometers at different offsets from the propane burner. Results are shown for the growth and onset of steady phases. Near the burner, radiative heat fluxes converge upon 120 to 140 kW/m^2. Away from the burner, the experiments with combustible ceilings (2 and 3) consistently show heat fluxes of c. 10 to 20 kW/m^2 greater than the non-combustible counterpart. This difference broadly coincides with that attributable to flames at the surface of wood, as reported by other authors [5], [6].

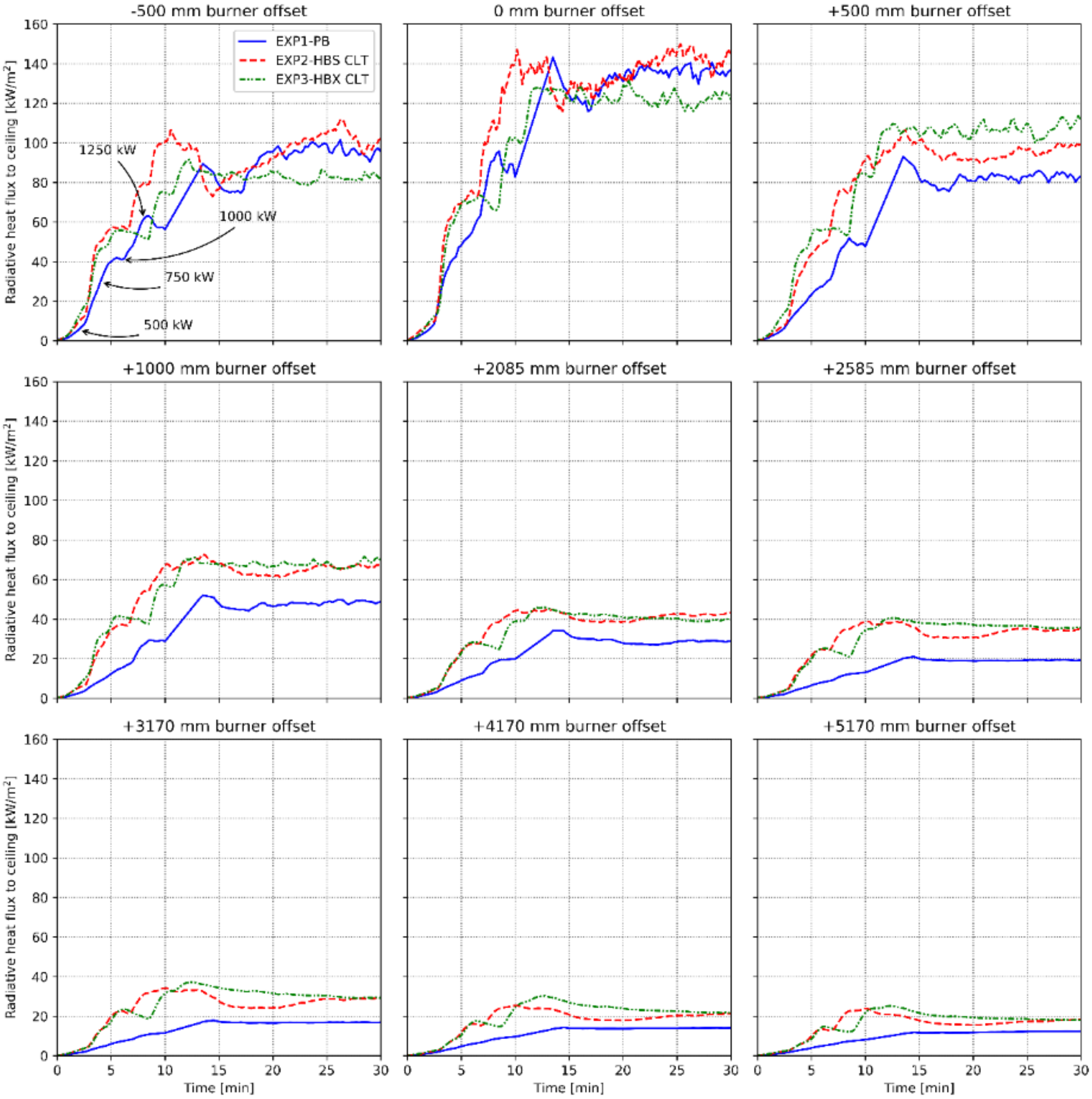


Figure 7. Radiative heat flux to the ceiling at different offsets from the burner for experiments 1-3 (burner heat release rates annotated in -500 mm offset).

Combustible ceilings and heat flux to the floor

The presence of extended flames at the ceiling is shown to correspond with increased radiative heat flux to the floor (relative to experiment 1), as shown in Figure 8. This is more pronounced at larger burner offsets and would, in practice, likely translate to more rapid fire spread through a large compartment.

Whilst there was no discernible difference between regular (HB S) and heat-resistant (HB X) PUR adhesives in respect of radiative heat flux to the ceiling (Figure 7), there is a difference for radiative heat flux to the floor. Away from the burner, radiative heat fluxes to the floor were substantially higher where HB S adhesive was adopted over HB X. As plots are limited to the growth and onset of steady phases, such a difference is not attributable to GLIF and warrants further investigation. Other outcomes from the STA project have identified that HB X may impact fire performance more complexly than simply mitigating GLIF [7]. The difference in edge-bonding condition between experiment 2 and 3 is also noteworthy.

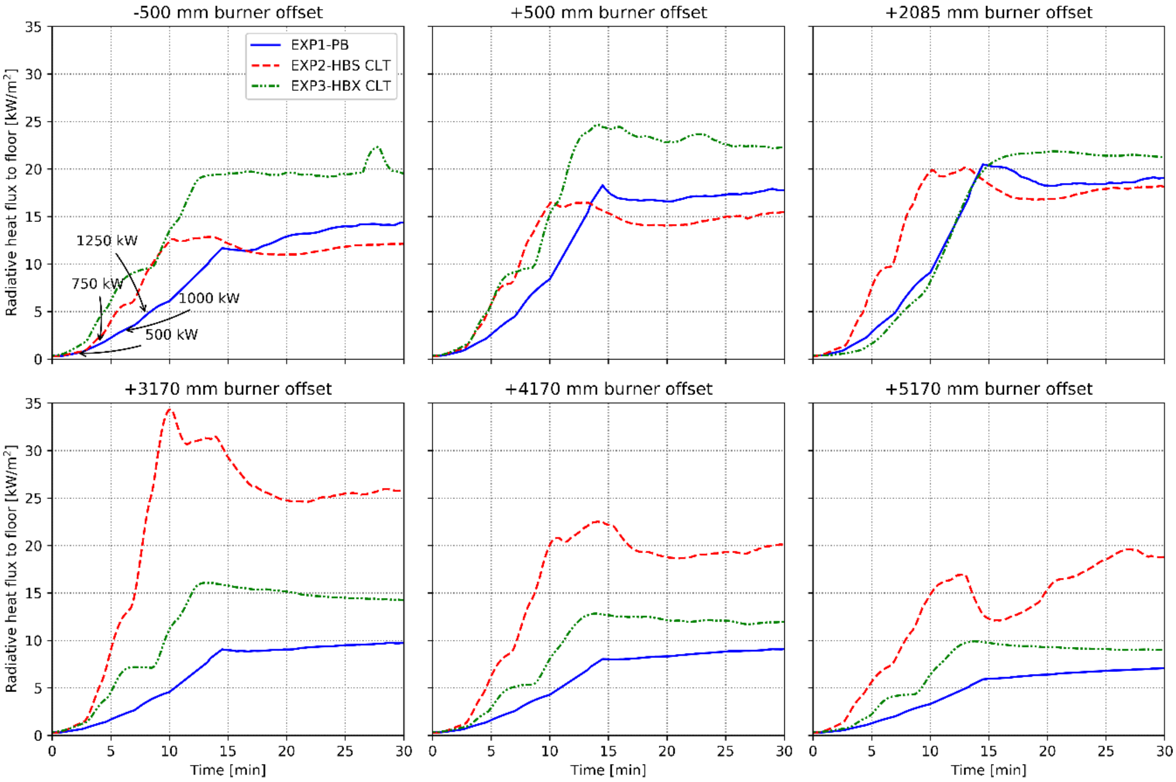


Figure 8. Radiative heat flux to the floor at different offsets from the burner for experiments 1-3 (burner heat release rates annotated in -500 mm offset).

Summary

This article has served to provide a brief update on the progress of the STA Special Interest Group project on mass timber compartments, summarising the motivations for and delivery of three large scale fire experiments, focussing on commercial type enclosures. Noting the primary objective of establishing if, for the specific case of exposed CLT ceilings (in commercial buildings), averting GLIF is a prerequisite for auto-extinction, it has been shown that extensive char fall off can occur in tandem with the cessation of flaming. Further analysis is required to better understand to what extent such a finding from the experiments translates to commercial buildings in practice. This will require a more thorough analysis of the data collected, with further publications expected in due course.

References

[1] Structural Timber Association, Structural timber buildings fire safety in use guidance. Volume 6 - Mass timber structures; Building Regulation compliance B3(1), V1.1. Structural Timber Association, 2020.

[2] D. Hopkin, M. Spearpoint, C. Gorksa, H. Krenn, T. Sleik, and M. Milner, ‘Compliance road-map for the structural fire safety design of mass timber buildings in England’, SFPE Europe, vol. Q4, no. 20, 2020.

[3] G. Ronquillo, D. Hopkin, and M. Spearpoint, ‘Review of large-scale fire tests on cross-laminated timber’, J. Fire Sci., p. 073490412110344, Aug. 2021, doi: 10.1177/07349041211034460.

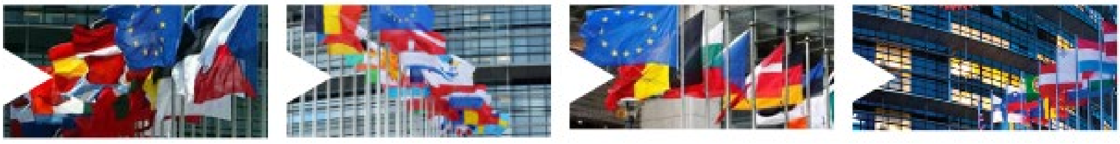
[4] Structural Timber Association, ‘CLT Special Interest Group’, 2021. http://www.structuraltimber.co.uk/sectors/clt-special-interest-group (accessed May 04, 2021).

[5] M. J. Spearpoint and J. G. Quintiere, ‘Predicting the burning of wood using an integral model’, Combust. Flame, vol. 123, no. 3, pp. 308–325, Nov. 2000, doi: 10.1016/S0010-2180(00)00162-0.

[6] D. Morrisset, R. M. Hadden, A. I. Bartlett, A. Law, and R. Emberley, ‘Time dependent contribution of char oxidation and flame heat feedback on the mass loss rate of timber’, Fire Saf. J., p. 103058, May 2020, doi: 10.1016/j.firesaf.2020.103058.

[7] D. Hopkin et al., ‘Experimental characterisation of the fire behaviour of CLT ceiling elements from different leading suppliers’, presented at the Applications of Structural Fire Engineering, Ljubljana, Slovenia, 2021.

SFPE EUROPE



Q3 2021 ISSUE 23 AN OFFICIAL PUBLICATION OF SFPE

The Transient Nature of Occupant Loads: A Case Study for a Small UK Office

By: Charlie Hopkin & Michael Spearpoint, OFR Consultants, UK

Background to office occupant loads

In the fire safety design of offices in the UK it is common for the number of potential occupants within the building to be estimated through the application of an 'occupant load factor' (sometimes referred to as a 'floor space factor'). This estimation of the occupant load is necessary to determine stair and exit capacities, support egress calculations, etc.

Spearpoint and Hopkin [1] note that the definition of occupant load is not universal, with NFPA 1 [2] describing it as *"the total number of persons that might occupy a building or portion thereof at any one time"*, the New Zealand Acceptable Solutions [3] as *"the greatest number of people likely to occupy a particular space within a building"*, and the Scottish Technical Handbook [4] as *"…the appropriate number of occupants in each space for normal circumstances"*.

Guidance in the UK, including Approved Document B (ADB) vol. 2 [5], BS 9999:2008 [6], and the Scottish Technical Handbook [4], recommends that an occupant load factor of 6 m^2/person be applied for offices. ADB [5] suggests that, as an alternative to using occupant load factors, the occupancy *"may be determined by reference to actual data taken from similar premises. Where appropriate, the data should reflect the average occupant density at a peak trading time of year"*. However, the public availability of this type of data, specifically for UK occupancies, appears to be somewhat limited.

To estimate a probabilistic distribution for the occupant load of a representative UK office building, Hopkin et al. [7] have previously applied US data from the studies of Milke and Caro [8] and Thackeray et al. [9]. A truncated normal distribution was proposed with a mean of 24.6 m^2/person, a standard deviation of 14.1 m^2/person, a minimum (i.e., highest density) of 0.5 m^2/person and a maximum (i.e., lowest density) of 101.5 m^2/person. However, Hopkin et al. acknowledged that office occupant loads, and associated design guidance for offices, will differ between the US and the UK.

In the absence of relevant data for UK offices, an alternative approach commonly taken is to utilise the number of desks / workstations / seats which the building occupier intends to place in the premises, considering that each desk is representative of a single occupant. A limitation of this approach is that it assumes all available desks will be occupied simultaneously, and that no additional occupants other than those assigned to desks will be present within the building at the time of evacuation. In practice, occupancies within the building may be far more transient. Some desks may not be occupied should staff be on leave, only working part-time, working from home, or attending external meetings. It is also possible that occupants other than those assigned to desks could be in the office temporarily for meetings, special events, etc.

The purpose of this article is to use an exemplar to briefly explore the variable nature of office occupant loads and thus provide some high-level context on common design approaches and assumptions. To achieve this, the article details a case study for a single UK office, in which occupancy data was recorded for an eight-week period.

Case study methodology

The case study office is based in Manchester, comprises a single level, and accommodates the staff of a fire engineering consultancy firm. A summary of the office details is presented in Table 1.

To determine the number of occupants in the office, a 'headcount' was taken on each hour between 07:00 AM and 06:00 PM (07:00 to 18:00) on weekdays (the range of typical office working hours for the consultancy). The data was recorded for an eight-week period in January and February 2020, prior to any then unforeseen lockdown impacts of the Covid-19 pandemic. In some instances, a headcount was not taken due to the individual responsible for counting being unavailable or otherwise occupied at the time.

Table 1. Summary of office used for the case study.

Item	Value	Additional comments
Office floor area	~200 m^2	The floor area includes an area for desks, an open plan kitchen and dining space, but excludes a separate meeting room.
Number of permanent staff	21-24	Staff numbers increased by three across the eight-week period that the study was undertaken. Most staff were full-time employees, with a few staff working part-time, two to three days a week.
Number of fixed desks	28	A greater number of fixed desks were available than permanent staff to accommodate for potential company growth, additional visitors, etc.

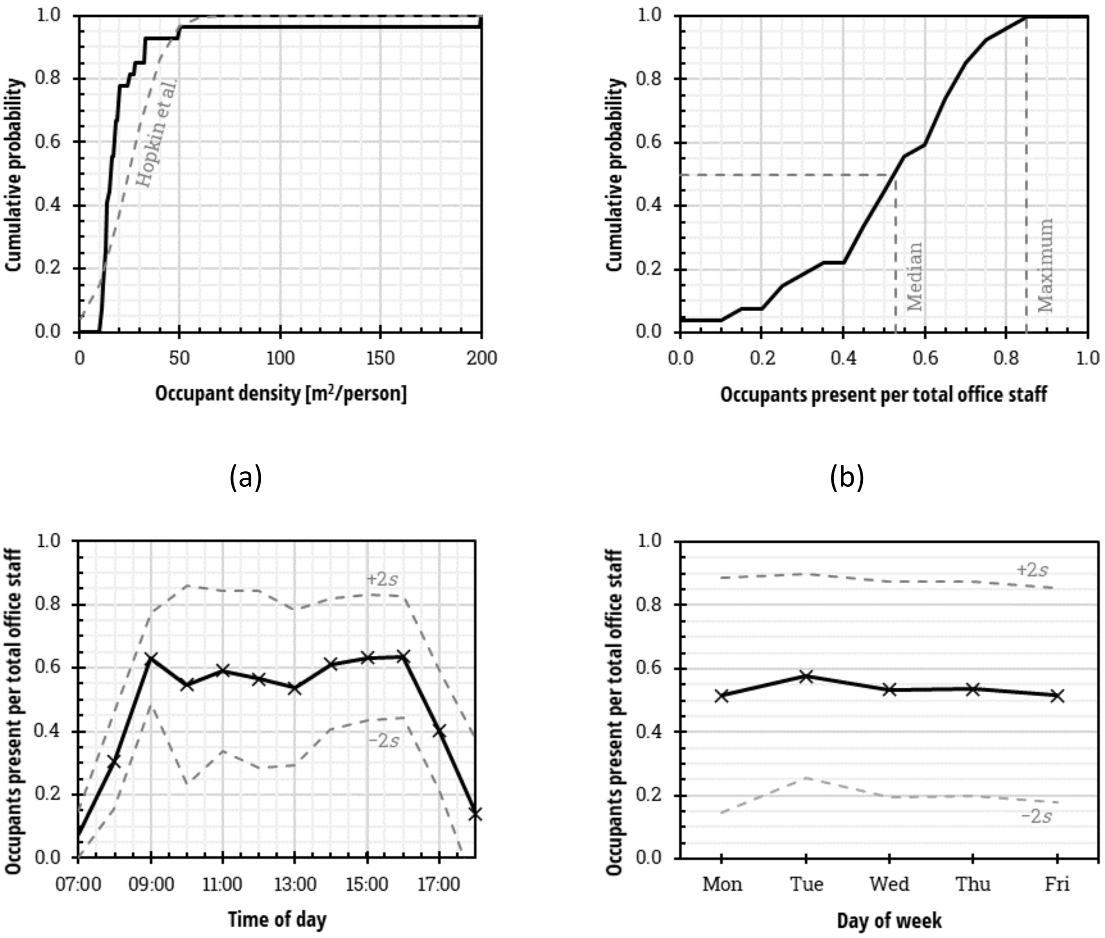
Item	Value	Additional comments
Available floor area per staff member	8.3-9.5 m^2/person	For this specific office, the floor area available per staff member was shown to be greater than the 6 m^2/person occupant load factor recommended in ADB. To achieve a value ≈ 6 m^2/person, nine visitors would need to be present in addition to the 24 staff.
Available floor area per desk	7.1 m^2/desk	As above, the available floor area per desk is greater than the 6 m^2/person ADB occupant load factor. To achieve 6 m^2/desk, an additional six desks would be needed.

Results

A total of 293 data points were recorded out of a potential 480 across the eight-week period, with Figure 1 providing a summary of the key results. Figure 1a and Figure 1b present the cumulative distribution functions (CDFs) for the occupant density and the occupants present per total office staff, respectively. The latter represents the number of occupants present (including any visitors) divided by the total office staff employed at the time the headcount was taken. The distribution function in Figure 1a has a mean of 21.8 m^2/person, similar to 24.6 m^2/person from the distribution of Hopkin et al. [7], discussed previously. The medians are less similar, with 16.0 m^2/person for the office distribution and 24.9 m^2/person from Hopkin et al. The standard deviation of the distribution is 26.6 m^2/person, presenting a greater extent of spread when compared to 14.1 m^2/person from Hopkin et al. From Figure 1b, it can be observed that at no stage within the eight-week period was the office at its full staff capacity, with the maximum being 85% of the staff in the office at a given instance in time. The overall median of occupants present per total office staff was 53%.

Figure 1c and Figure 1d provides the average (mean) values for occupants per total office staff by the time of day and the day of the week, respectively. The dashed grey lines indicate two standard deviations (s) above and below the average values (i.e., the 5th and 95th percentiles when assuming a normal distribution). These figures highlight the general variability of the number of occupants in the office over time. Between 07:00 and 09:00, the number of occupants increases, subsequently maintaining an average in the region of 54% to 64% (per total office staff) up to 16:00 before decreasing after this time. In the 09:00 to 16:00 period, two standard deviations, above and below the average value, range from 23% ($-2s$) up to 86% ($+2s$). For the day of the week, there is less of a clear trend, although it appears that more people were in the office on Tuesdays (an average of 58%) compared to other days (e.g., 52% on Mondays). Again, the two standard deviations above / below the average is wide ranging, from 15% ($-2s$) up to 90% ($+2s$).

The results provided are for the occupants present per total staff. However, it is important to highlight that the total number of staff (21-24) is fewer than the number of desks available within the office (28), and thus the proportions would be lower if the number of desks were instead used as the point of reference.



(a)

(b)

(c)

(d)

Figure 1. (a) CDF for the occupant density; (b) CDF for the occupants present per total office staff; (c) average occupants per total office staff by the time of day; and (d) average occupants per total office staff by the day of the week.

Discussion and conclusions

This article briefly summarises a case study of the single storey office of a fire engineering consultancy firm, where the number of occupants in the office was recorded for an eight-week period. The results of the study highlight the variability in the occupancy by the time of day and the day of the week, as well as indicating that the office was never fully occupied to either its full staff numbers or desk capacity. A median of 53% of occupants per the total staff were present in the office at a given time, with a maximum of 85%.

A potential implication of the data presented in this article is that the common UK practice of utilising the number of desks or seats as a representation of the occupant load is a 'conservative' design approach. However, it is important to recognise that this single office is by no means representative of the wide-ranging behaviours which could be observed across different offices in the UK, and its observations should not be applied to design without very careful consideration. The observations in this article could be unique to the office in question, and the transience of an office occupant load will be dependent on several factors, including seasonal variations, the office culture, and the type of work that is being delivered. For example, it may be hypothesised that a call centre is likely to have a greater number of occupants remaining in the office and at their desks than an engineering consultancy, where the staff are regularly outside of the office, such as on site or attending external meetings.

It would be beneficial to collate more data on office attendance in the UK (and elsewhere), by the time of the day, the day of the week, etc. This would help to develop a greater understanding on the transience of office occupant loads for different office practices and cultures. This topic has become even more pertinent with the ongoing debate around the likelihood of offices returning to previous working conditions post-pandemic, or whether hybrid working, working from home, flexible working, etc., could become the ‘new normal’ [10]. Such changes to working practices could substantially alter the utilisation of office footprints and the associated occupant loads. With the collection of more data across the coming years, it is possible that existing assumptions around fire safety design of offices could be revisited.

References

[1] M. Spearpoint and C. Hopkin, ‘A review of current and historical occupant load factors for mercantile occupancies’, *Journal of Physics: Conference Series*, vol. 1107, pp. 1–6, 2018, doi: 10.1088/1742-6596/1107/7/072005.

[2] NFPA, ‘NFPA 1, Fire Code, 2018 Edition’, National Fire Protection Association, 2017.

[3] Ministry of Business, Innovation & Employment, ‘C/AS2, Acceptable Solution for buildings other than Risk Group SH’, New Zealand Government, Jun. 2019.

[4] Scottish Government, ‘Building Standards Technical Handbook 2019: Non-domestic’, 2019.

[5] HM Government, ‘The Building Regulations 2010, Approved Document B (Fire Safety) Volume 2 (2019 edition, as amended May 2020)’, 2020.

[6] BSI, ‘BS 9999:2008 Code of practice for fire safety in the design, management and use of buildings’, BSI, London, 2008.

[7] D. Hopkin, R. Van Coile, C. Hopkin, I. Fu, and M. Spearpoint, ‘Transient reliability evaluation of a stochastic structural system in fire’, presented at the 16th International Probabilistic Workshop, 2018. doi: 10.1002/best.201800059.

[8] J. Milke and T. Caro, ‘A survey of occupant load factors in contemporary office buildings’, *Journal of Fire Protection Engineering*, vol. 8, no. 4, pp. 169–182, 1996, doi: 10.1177/104239159600800402.

[9] T. Thackeray, T. Muha, and T. Wood, ‘Evaluating occupant load factors for business operations’, Worcester Polytechnic Institute, Worcester, MA, Undergraduate Project Report, 2012.

[10] BBC Worklife, ‘Coronavirus: How the world of work may change forever’, Oct. 23, 2020. https://www.bbc.com/worklife/article/20201023-coronavirus-how-will-the-pandemic-change-the-way-we-work (accessed Jun. 16, 2021).