SFPE EUROPE

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SFPE Europe Magazine

3rd Quarter - 2025

A word from the Editor

All,

Third Issue of the year and so far we have given you an array of different articles that we hope are useful and interesting for the profession.

In this Q3 issue you will, as always, find a mixture of highly technical articles, but as in former issues you can see that there is always something about emerging technologies and new risks. In future issues we will to some degree keep focus on this as it is where knowledge and information is vital for the fire safety professionals, i.e. you.

We are just a few days away from celebrating the Annual Conference in Vancouver, if you still haven't signed up for that one, see this as friendly reminder. The program looks amazing, the networking opportunities outstanding and very important I am sure that all the attendees will have a really good time.

Back to the articles, please have a look and read the ones that you believe will be useful or just interesting to you.

If there are readers out there that feel that you have an important subject that you 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 December.

Yours sincerely,

Jimmy Jönsson, Managing Editor

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A Message from the SFPE Europe Chair

Dear SFPE Europe members and all those interested in Fire Safety,

One of the key goals of SFPE Europe is to promote the use of fire safety engineering based on a scientifically sound framework.

To support this mission, SFPE Europe will host a webinar titled “The Importance of Fire Safety Engineering in a Developing Society” during European Fire Safety Week on November 3rd .

During the webinar, we will:

- Introduce SFPE and its role in advancing fire safety engineering.
- Highlight the importance of core competencies, with examples from the European International Master of Science in Fire Safety Engineering program.
- Discuss current developments in fire safety engineering standards.
- Emphasize the value of using science-based fire engineering approaches in developing regions.
- Explore the connection between fire safety and sustainability.

Presenters during the webinar will be Robert McNamee, Eulalia Planas, Kees Booth, Ralf Bruyninckx and Margaret McNamee.

I hope you like to join!

Best regards,
Robert McNamee
SFPE Europe Chair

SFPE Europe's mission: “SFPE.Europe.is.leading.the.profession.as.a.neutral?international.non_profit.organization.to.define?develop?and.advance.the.use.of.fire.engineering?fire.protection.engineering?and.fire.safety.engineering.best.practices·.expand.the.scientific.and.technical.knowledge.base·.and.educate.the.global.fire.safety.community?in.order.to.reduce.fire.risk

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Environmental impact of lithium-ion BESS incidents compared to other types of fires

By: Caroline Gaya, Arnaud Bordes, Anis Amara, Karen Perronnet, Amandine Lecoqo and Benjamin Truchot, INERIS, France

By: Joshua Lamb, Loraine Torres-Castro, Sandia National Laboratories, USA

The following is a reprint of the Executive Summary of a report published by the Fire Protection Research Foundation https://www.nfpa.org/en/education-and-research/Research/Fire-Protection-Research-Foundation/Projects-and-Reports

The usage of lithium-ion batteries is rapidly advancing across various applications, including smartphones, laptops, electric micro-mobility devices, and stationary battery energy storage systems (BESS). Among these, BESS have the unique capability to cover a wide range of energy needs, with capacities ranging from several hundred kWh for residential applications to several MWh in industrial cases. However, the significant onboard energy associated with BESS raises safety concerns, particularly regarding the potential environmental impact of fires. These concerns are especially relevant given the rapid development of the lithium-ion market. If appropriate attention is not given to safety assessments, design selection, and mitigation practices in the rush to keep pace with market demands, the risks of fire (and, in some cases, explosion) could increase. Although notable progress has been made in reducing the failure rates of BESS, the number and scale of these systems have surged dramatically. Consequently, large BESS fires often capture public attention, as seen in the recent Moss Landing fire in January, 2025. Public concern is also growing regarding the potential effects of battery fires on human health and the environment, particularly in terms of air quality, water resources, and soil health. Despite the acknowledgment of these issues, there remains a significant gap in assessing the true impact of such fires on public health.

To assess the environmental impact of BESS fires, it is essential to establish a comprehensive understanding of the potential emissions generated by such incidents. This study, titled “Environmental impact of lithium-ion BESS incidents compared to other types of fires” aims to highlight the current state of knowledge regarding emissions from BESS fires and propose an initial dataset of emission factors specific to these events.

To meet these emissions characterization objectives, the first step proposed for this study was to provide a comprehensive description of a BESS, including an overview of the materials used, their distribution, and their configuration. BESS systems enable the storage and delivery of energy on demand, facilitating the energy balance required by grid-connected systems (e.g., renewable intermittent energy production devices such as photovoltaic systems) or reinforcing the energy grid through peak shaving and responding to user demand. Each BESS system consists of a combination of electrochemical cells that, depending on the chosen configuration, meet specific voltage, current, power, and energy requirements.

BESS Material Composition

A BESS is composed of two parts: the components related to the electrochemical cells (such as the anode, cathode, electrolyte, and separator), which account for 60 percent of the BESS mass, and those unrelated to the cells [such as the connecting tabs and cables, battery management system (BMS), casing, cooling systems, etc.]. In summary, the main materials that make up a BESS include metallic compounds (which may include nickel, manganese, cobalt, lithium, iron, aluminum, copper, steel); carbonaceous species; binder materials, including PFAS, plastic components [e.g., polyethylene terephthalate (PET)], non-aqueous electrolytes (such as carbon-based solvents with lithium salts that also contain fluorine), and electronic components. It is worth noting that the composition may depend on the specific system, especially in regard to the selected battery chemistry [with lithium iron phosphate (LFP) being the most widely used chemistry in BESS compared to nickel cobalt aluminum (NCA) and nickel manganese cobalt (NMC)].

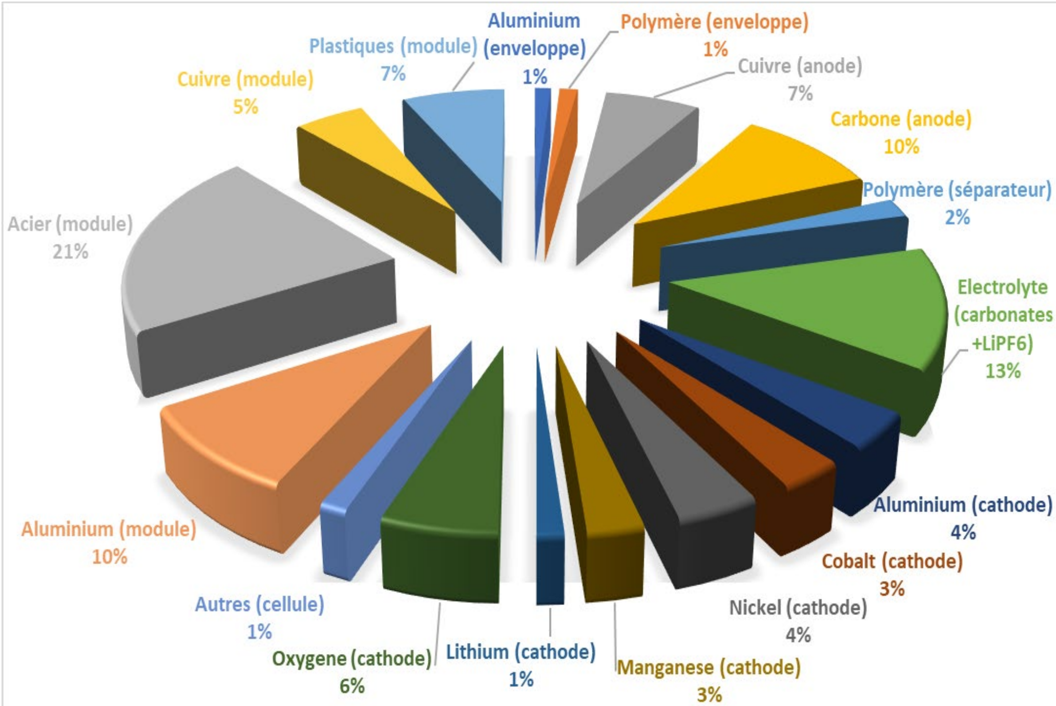

Figure 1: Material Compositional Breakdown of NMC Lithium-ion Battery.

Emission Pathways and Fire Scenario Development

These components, or their degraded forms, can become exposed to the environment once a BESS fire is triggered and can potentially lead to pollution through various pathways:

- *Emissions to air (smoke plume sedimentation).*
  Pollutants carried by the fire or smoke plume can deposit on land and in water, with some dilution over distance. Gaseous emissions to air account for the majority of emissions, however, distributions are heavily weather dependent. Some example species may include acute toxicants, soot, aerosols, particles or organic species, such as VOC, PAH, dioxins/furans, etc.
- *Emissions to water (runoff from firefighting activities).*
  Water used to suppress the fire can transport emissions from damaged batteries into the environment.
- *Emissions to soil (fire debris or residue).*
  Residual materials and contaminants from burnt batteries may contribute directly or indirectly to soil and water pollution after deposition, landfill, or recycling.

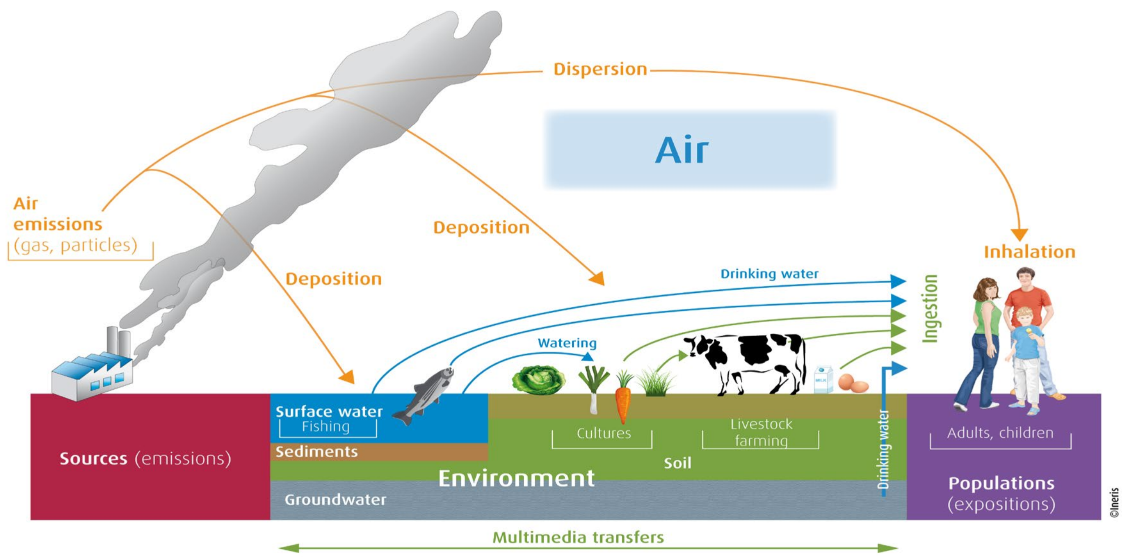

Figure 2: Emission Pathways

The commonly emitted compounds and particulates released during a LIB BESS fires were found the impact various environmental pathways, as summarized in Table 1.

Table 1: Impacts of common emitted contaminants from BESS fires on various environmental pathways

	Air	Surface Water	Ground Water	Sediment	Soil
Halogenated acids (HX)	☑				
Metals	☑	☑	☑	☑	☑
Nitrogen Oxides (Nox)	☑				
Particulates	☑	☑			☑
Sulfur Oxides	☑				
Volatile Organic Compounds (VOC)	☑				
Perfluorinated compounds (PFC)		☑	☑	☑	☑
Polychlorinated biphenyls (PCB)	☑	☑		☑	☑
Polychlorinated dibenzodioxins (PCDD)	☑	☑		☑	☑
Polychlorinated dibenzofurans (PCDF)	☑	☑		☑	☑
Polycyclic aromatic hydrocarbons (PAH)	☑	☑			☑

While these emission pathways are well identified, determining the emissions to be considered for BESS is not trivial, as it depends on multiple parameters (such as the combustion mechanism, particle size distribution, BESS design, and lithium-ion cell composition). Because environmental contamination depends on a fire’s characteristics, defining the fire scenario is a crucial issue. Given that numerous fires have occurred in BESS during the last decade, it makes sense to use lessons learned from those incidents to study the emission pathways. To provide an accurate overview of BESS fires, an analysis of several incidents that offer insights into the environmental impact of BESS fires was performed. Incident reports also provided the opportunity to study the methods used and develop recommendations . For instance, after a fire at a battery recycling facility in Saint-Quentin-Fallavier (France, 2012), no heavy metal pollution was found in the river into which rainwater run-off was poured (most likely due to heavy rainfall dilution). The report for the Perles-et-Castelet fire (France, 2020) noted the need to collect wastewater after the extensive use of water directly onto the container. The BESS fire in Geelong (Australia, 2021) demonstrated a common firefighting method of spraying water around the BESS rather than directly onto the burning container while still collecting the water for treatment. The Morris fire (USA, 2021) led to legal action regarding the release of pollutants into the air and water. The Hwaseong case (Korea, 2024) highlighted the human risks associated with battery fires, as it led to the deaths of 22 people. Meanwhile, the Moss Landing site (USA) has now reported three large incidents in 2021, 2022, and 2025 with reported environmental impacts. As illustrated through the highlighted incidents, there are disparate results and inconsistencies in terms of the claimed environmental impact of BESS fires. While the majority of BESS fire scenarios tend to correspond to failures within a single container, cases of fire propagation and explosion incidents have been reported and should be accounted for. In addition, while heat release rates with BESS fires are moderate compared to similarly sized fires of other types, that does not necessarily mean there is less of an environmental impact, as a high concentration of contaminants tends to be deposited in the immediate vicinity of a BESS fire due to lower smoke dilution. Although many organizations have reported minimal health or environmental impacts following BESS fires, it should be cautioned that many incidents have lacked real-time monitoring. And in some cases, data was collected after plumes dispersed, key pollutants were not captured, baseline data was lacking, or weather impacts were overlooked. Limitations in available data should always be recognized and accounted for when defining the environmental impact of a BESS incident.

Emission Factor Development

To assess the emission factors, a review of scientific literature primarily found data obtained from small-scale cases. Whether these results can be used to predict the effects of larger fires is sometimes questioned; however, these results still provide insightful data and can occasionally be extrapolated to represent larger fires. For instance, a study evaluating extinguishing water pollution after thermal runaway of NMC batteries considered the dilution ratio of real fire cases and highlighted that the pollution could potentially affect nearby water ecosystems based on the concentrations found.

More generally, the state-of-the-art review yielded a broad overview of the pollutants emitted by BESS fires, summarized below:

- **Gaseous emissions:** Toxic and flammable gases are released during thermal runaway. The composition of the gaseous mixture evolves depending on many factors (such as battery chemistry, state-of-charge, and thermal runaway progression) and may include liquid electrolyte vaporization; carbon monoxide; carbon dioxide; dihydrogen; hydrocarbons (like methane, ethane, ethylene); polycyclic aromatic hydrocarbons (such as benzene, toluene, styrene, biphenyl); fluorinated compounds (especially hydrogen fluoride and phosphoryl fluoride); and other toxic species such as acrolein, hydrogen cyanide, ammonia, and sulfur dioxide. Notably, the literature review underscores the lack of studies analyzing polycyclic aromatic hydrocarbons (PAHs) and volatile organic compound (VOC) emissions.

- **Aerosol emissions:** The aerosols emitted by BESS fires are made up of particles ranging from micrometers to nanometers, combined with liquid droplets. Depending on the battery chemistry, different types of particles have been observed (in terms of morphology, composition, and quantity), resulting in aerosol solid particles composed of a mixture of metallic (Ni, Al, Cu, Co, Mn, and Li) and non-metallic (C, O, F, Si, P, and S) species. The risk of environmental pollution and threat to human life cannot be dismissed, as some aerosol particles contain toxic elements and can be inhaled due to their size. In addition to aerosol particles, solid particles larger than a millimeter were also found.
- **Wastewater:** Generally, wastewater is loaded with ions, metallic elements, and organic compounds, and the resulting toxicity is significantly affected by the water's exposure to battery fragments and smoke, as well as by the resulting dilution ratio. Consequently, water pollution greatly depends on the intervention method selected (whether water is applied directly to the battery/system, to the surroundings, or used via an immersion tank). Available studies highlight the potential sources of pollution linked to wastewater.

While the literature provides awareness of the pollution caused by battery thermal runaway, it is difficult to define the lithium-ion battery emission factors due to a lack of large-scale data; insufficient information (e.g., gas concentrations without total emission volume); variations in gas analysis methods; and the wide range of lithium-ion battery (LIB) chemistries and formats considered. Moreover, the absence of mass loss reporting for BESS fires impedes the definition of their emission factors in grams of emitted gas by gram of fuel burned (typically performed in combustion research).

A methodology for calculating LIB emission factors was proposed, normalizing the emission factor to the nominal energy stored (expressed in Wh). The values were normalized based on data provided in literature or by using a generic LIB value (160 Wh/kg for a full battery and 250 Wh/kg for a cell or group of cells without external systems). Three approaches were used to calculate emission factors:

- The emission factors considered for building the database were estimated directly from the scientific papers reviewed, with verification of the measurement methods used and the test conditions performed.
- Emission curves from scientific papers were integrated, when available, to estimate the total amount produced by a given gas. The results were then normalized with the potential available energy based on the sample mass.
- Results from previous in-house studies were also considered.

Emission factors for LIBs, obtained using this methodology on the available data, were then compared to those for hydrocarbons, internal combustion engine (ICE) vehicles, battery electric vehicles (BEV) vehicles, and tires, leading to the following observations:

- Emission factors for CO and CO2 are not significantly different for LIBs compared to other fuels, such as hydrocarbons, or vehicles (with a cautionary note that the CO/CO2 ratio for LIBs does not directly illustrate the fire ventilation conditions, as LIBs release CO and O2 in vented gases).

- Nitrogen oxide emissions appear to be higher for LIBs (though this requires further investigation). Regarding halogenated acids, as expected, the emission factor for hydrofluoric acid (HF), while not necessarily high, is greater for batteries and BEVs than for ICE vehicles.
  - Both halogenated acids and nitrogen oxides (NOx) are particularly concerning as they strongly pollute soil and water and deplete the ozone layer.
- Particle matter production also appears to be lower for LIBs. However, it is important to note that the composition of this particle matter, or more significantly, the particles, likely differs between carbon-based fuels and LIBs, mainly due to the presence of metals in the particle matter from LIBs.
  - One of the key potential pollutants with long-term effects for LIBs may be metals. Fire tests underscore a significant emission factor for this type of fuel, much larger than for other fuels, even tires, which are one of the classic fuels with the largest metal emission factors.
  - Among the metals found, cobalt and nickel are particularly concerning due to their toxicity to humans and the environment.
- The emission factors for VOCs and PAHs for LIBs seem to be of the same order of magnitude as those observed for other fuels.

These findings are graphically summarized in *Figure 3*.

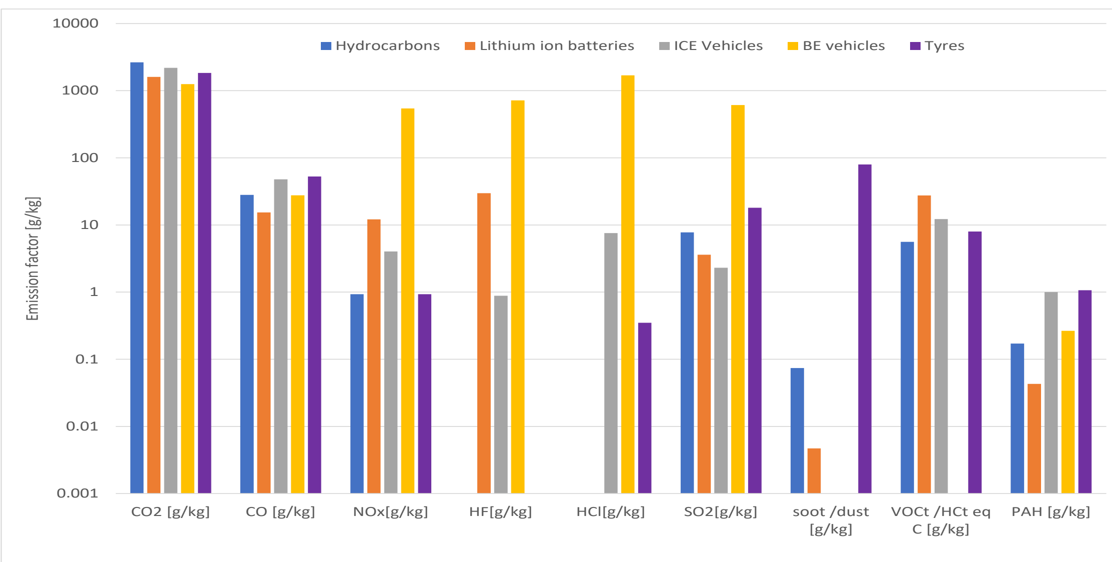

Figure 3: Comparative Emission Factors

Summary observations, knowledge gaps and next steps

Several key issues were raised, including the need to clarify the emission factors for each chemical composition of LIBs. In addition, as metallic pollution is a particular concern with LIBs, it was decided that a specific screening of metallic species should be implemented after a LIB fire, as each metal impacts the air and water in different ways. Guidelines were also provided for collecting relevant information for improving emission factors. For instance, continuous gas analysis and mass loss rate measurements were recommended, as were studies dedicated to assessing battery environmental impact. The dependence of emission factors on battery chemistry, triggering methods, and system configurations also warrants further investigation in future studies.

To further study the environmental impact of LIBs, fire modeling based on previously defined emission factors and considering three representative cases was conducted (covering past events and anticipating future potential events with large BESS). The resulting scenarios for LIBs were compared to the same scenarios for hydrocarbons, PVC, and tire storage (for a general overview, as the emission factors remain uncertain). The main findings from the simulations indicated that LIB fires generally have limited thermo-kinetic energy in the fire plume, resulting in reduced atmospheric dispersion. Consequently, PAH and similar product deposits may be higher for a LIB fire than for a classic fuel fire with the same emission factor magnitude, mainly due to this lower atmospheric mixing. In addition, metals appear to be one of the most critical pollutants when considering potential deposits from LIB fires. A cautionary note remains, as these results should be analyzed in light of the difficulties encountered in defining robust emission factors for specific pollutants emitted by LIB fires, particularly metals, which remain a significant unknown parameter in assessing the environmental impact of LIB fires.

As with any fire, BESS fires represent a potential source of environmental pollution. Several pathways exist for contamination, which highly depend on the specific scenario and the firefighting methods used. Emission factors for LIBs were proposed but rely on limited available data. The main conclusion of this study is that the emission of particles containing metallic compounds caused by LIB fires represents a significant concern specific to LIB fires. Other toxic species emissions, such as PAHs and VOCs, were reported and require further analysis. Improvements in measurement and reporting values were suggested for future studies to enhance knowledge on LIB emissions.

While emission factors strongly influence environmental impact, they are not the only parameter. Indeed, the dispersion of the plume is also a critical factor. A particularity of LIB fires highlighted in this study is the limited dilution of the fire plume due to the kinetics involved, which affects the indirect contamination of soil and water. Finally, more extensive analyses of contamination in real cases and large-scale testing are recommended to broaden and gather more consistent data for future environmental impact assessments of LIB fires.

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Do you have a fire door or a fiery door? – Fire load contributions of fire doors and other construction systems

By: Ryno van Wyk and Dirk Streicher, Ignis Fire Testing, South Africa

This article presents a short discussion considering the contribution of doors to heat release rates and fire intensity in an enclosure. The discussions also apply to other construction systems that incorporate combustible material. It is almost inherently assumed that fire doors make a building safer, and this is typically the case. However, what happens if they can also make the fire more intense due to the contribution of their outer combustible skins or core? In a large enclosure with many stored materials, this contribution from doors may be relatively small. However, in a small enclosure, such as a hotel room, it could have a more significant impact, as highlighted below, where the contribution can be approximately 120 kW/m^2 or even higher. Hence, this short article presents some musings of fire testing laboratory staff who have observed the impact of tested doors on furnace behaviour and highlight it as a discussion piece.

The purpose of a fire door is to serve as a fire division between two rooms, known as fire compartments. Fire doors are tested in a furnace that complies with EN 1363-1, which describes the requirements for the furnace in which the fire door is tested to maintain consistency throughout testing laboratories. The performance criteria for a fire door are stated in EN 1634-, which outlines the requirements for a fire door to pass based on three criteria: integrity (E) and insulation (I) or radiation (W). The integrity criteria assess any compromise on the door with respect to openings or gaps to allow hot gases to pass through. Insulation and radiation assess the door's ability to provide sufficient insulation to prevent ignition of materials on the unexposed side of the fire door. An element that must carry load is also required to satisfy structural resistance requirements (R).

Based on the criteria mentioned above, fire doors obtain a fire rating that indicates the fire resistance of a specifically tested door assembly. This can typically be a rating such as EI60, which implies that the door passed the integrity and insulation criteria according to the standard for 60 minutes while being exposed to the standard fire curve. According to this result, the performance of any two fire doors with an EI60 rating is the same with respect to serving as a fire division according to the EN standards. However, the standards do not specify the fire performance of a fire door concerning the contribution to the fire severity on the exposed side, i.e., on the fire side. Can a fire door, or other system, influence the fire load in a fire compartment?

Various fire door tests have been conducted at Ignis Testing in a vertical furnace manufactured according to SANS and EN standards, as shown in Figure 1, providing data and experience to analyse the effect of a fire door on the furnace temperature control. The furnace shown is fired using diesel burners, which are controlled with a Supervisory Control and Data Acquisition (SCADA) system to follow the specified standard time-temperature curve. When conducting tests on doors, there have been cases where the door burnt so severely that the furnace burners could virtually be turned off as the door ‘fired’ the furnace. Hence, it was decided that more investigation was required. Benchmark tests were conducted to determine the amount of energy required to heat the furnace to the standard fire curve without any sample – i.e. a blank, relatively inert closure was included to provide very low energy losses. Thereafter, a combustible chipboard door was included because it gave a fire performance similar to some of the doors previously tested (and since no proprietary system could be used). Also, a timber door with a vermiculite core was considered. The latter would normally be considered a good fire door as the non-combustible core limits fire spread and provide a good fire resistance rating.

Figure 1: Vertical furnace and SCADA system at Ignis Testing

Figure 2 displays the total energy required to heat the furnace to the standard fire curve in three cases: 1) Furnace benchmark – no sample (green), 2) Voided chipboard core – combustible (blue), and 3) Vermiculite core – non-combustible (orange). The furnace is heated with two diesel burners, each with a power range between 100kW and 300kW. The energy input into the furnace is calculated based on the diesel consumption of the diesel burners. The solid lines in Figure 2 display the energy input from the burners for each case. Assuming the benchmark case represents the energy required for no sample heating, the change in energy consumption can be calculated by subtracting each door test's energy consumption from the benchmark test. The dashed line is the difference between the benchmark test and the energy consumption required by the test specimen for each core, respectively. Hence, the dashed curve indicates the total energy that a sample “contributes to the fire”.

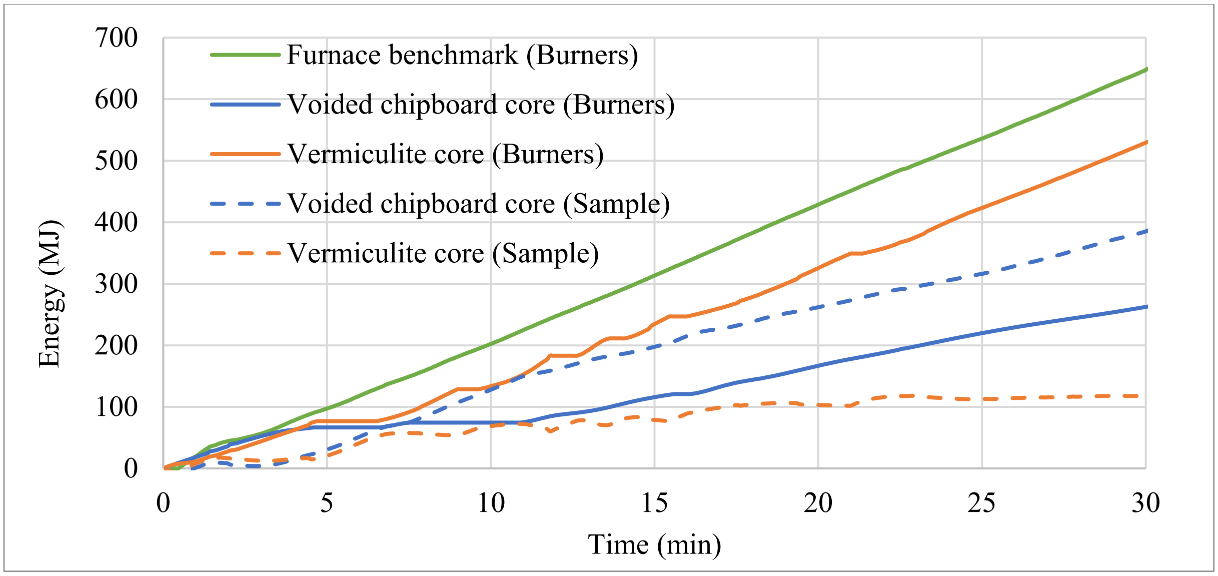

Figure 2: Total energy calculated for two fire doors based on a benchmark test with no sample. The solid lines represent the energy input from the burners for each test, respectively. The dashed lines represent the calculated energy contribution, which is the subtraction of the benchmark test and each door test, respectively.

For comparative analysis, the energy contribution per unit area (MJ/m²) for each fire door mentioned above is plotted against each other as shown in Figure 3. From this data, it is clear that the energy contribution for the combustible core is up to four times more than the non-combustible core.

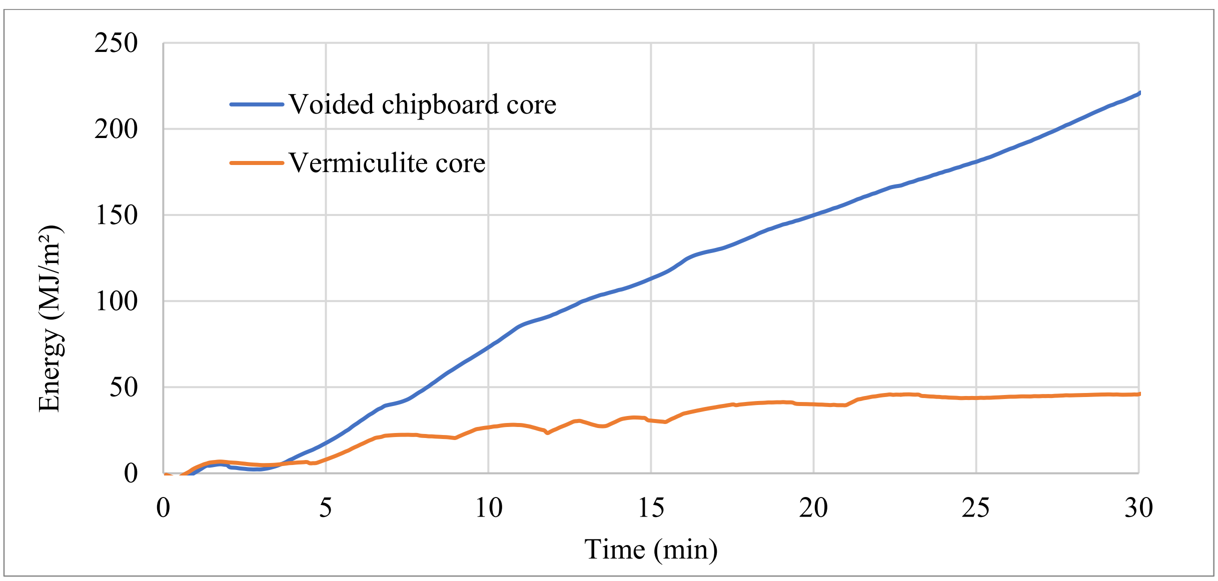

Figure 3: Calculated energy released per unit area comparing fire doors with combustible and non-combustible cores, respectively.

Figure 4 presents the heat release rate per unit area (HRRPUA) calculated for each fire door based on the energy contribution over time. At approximately two minutes, there is a small peak in the HRR; thereafter, the HRR increases to a certain point and remains there until the end of the test. Generally, the core of a fire door is laminated with a combustible skin such as MDF, HDF or commercial plywood, as shown in Figure 5, which presents a cross-section of a typical fire door assembly. In the first three minutes, the skin is heated until it reaches the critical heat flux, resulting in the skin's burning off. Thereafter, the core is exposed to the heat flux in the furnace. Skins produce additional fire load, albeit for a short period and with a low total amount of energy, except that skins produce a localized HRR peak as shown in the graph below. The effect of a combustible core, such as a particle board core, will add a significant amount of additional energy for an extended period. This effect is enhanced when a voided core is used due to the additional surface area of the voids. Additional surface area will increase the total heat release due to the integral of the HRR multiplied by the exposed area. Ultimately, a HRRPUA of 120 kW/m2 for a 2 m^2 door leads to a 250 kW contribution to a fire which is not a trivial amount, when design fires may be in the order of 2-5 MW. If there are multiple doors, or double doors, the contribution will increase accordingly.

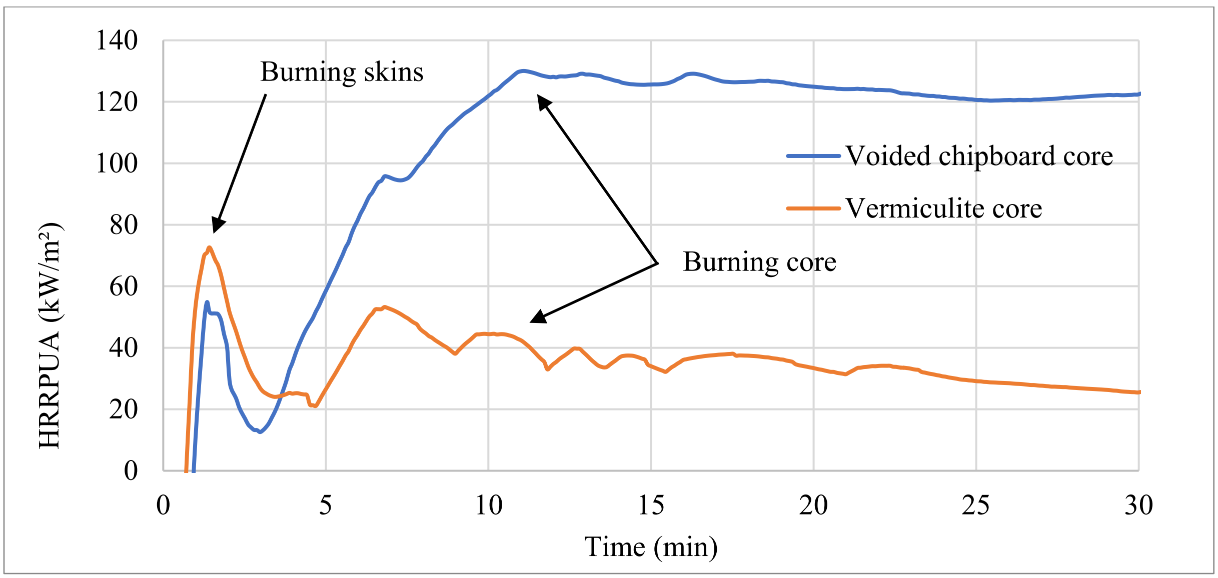

Figure 4: Total HRRPUA calculated based on the sample energy contribution over time.

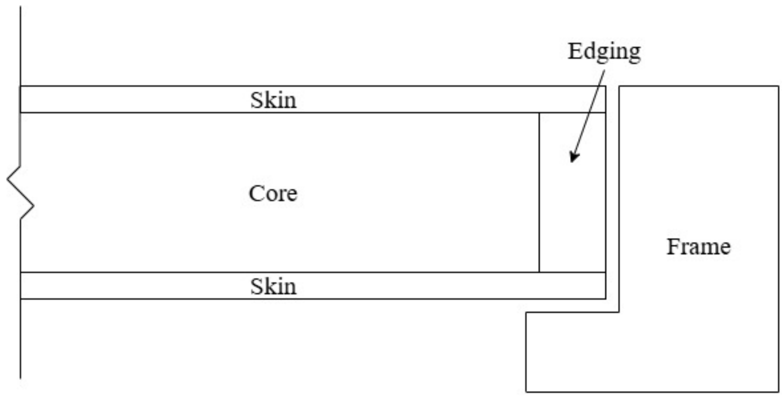

Figure 5: Plan view of a cross-section of a typical fire door assembly. The edging is fixed around the perimeter of the core, and the skins are glued on both faces of the door leaf.

In general, the assessment criteria are based on the performance of a fire door on the unexposed side of the fire test. This includes the above-mentioned integrity and insulation criteria, which assess the ability of the fire door to prevent fire spread and to serve as a “fire safe” division between two building compartments. Figure 6 displays photos of the exposed surface (fire side) of a typical non-combustible and combustible fire door. These photos were taken after the skin burned off, and only the core being exposed to the fire. These photos clearly indicate the difference between the flames and fire behaviour of each door on the exposed side of the furnace.

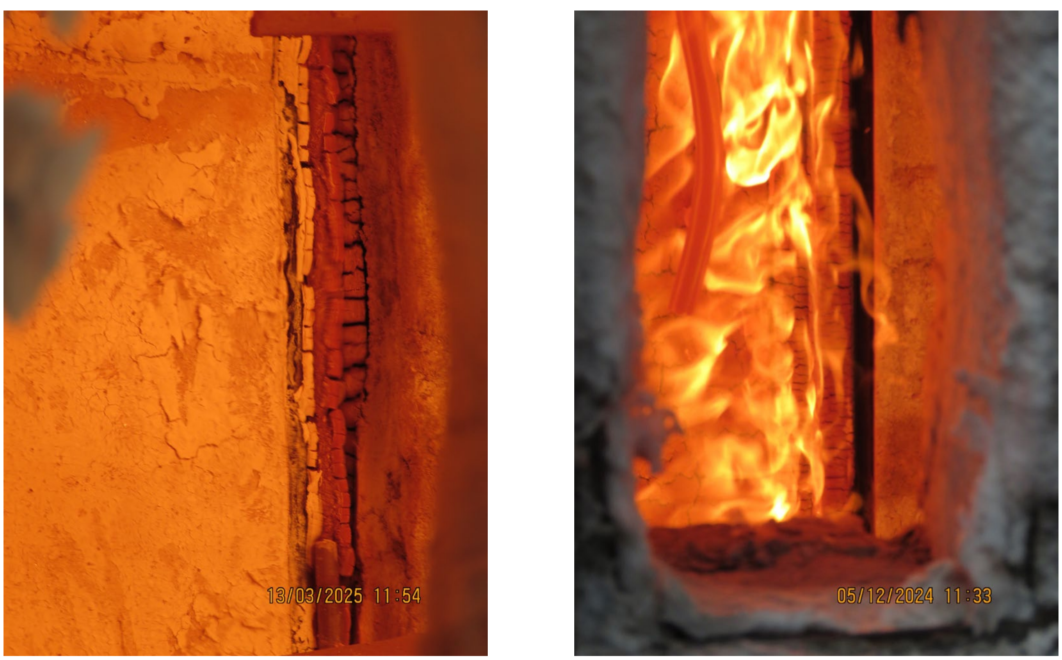

Figure 6: Photos of the exposed face of a typical non-combustible fire door (left), and a combustible fire door (right).

In conclusion, the fire load contribution of fire doors is not taken into consideration when fire doors are specified for their intended use. Two fire doors with the same fire rating do not necessarily behave the same with regard to the fire load contribution to a fire compartment. The assessment of fire doors according to existing standards also does not take the fuel load of a fire door into account. This work presents a concern regarding some fire doors themselves, with them being the division between fire compartments, while contributing to the fire load. The assessment of the energy contribution of fire divisions could be included in the existing standards, which can be beneficial to a design engineer determining the fire load in a building. The impact of the magnitude of the impact of such door combustibility will range widely depending on the room geometry and fire scenarios considered.

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Understanding pre-movement time and movement speeds in hospital evacuations

By: Paul Geoerg, Akkon Hochschule für Humanwissenschaften, Germany
Luke de Schot, University of Canterbury, New Zealand
Ruggiero Lovreglio, Massey University, New Zealand

This article condenses a study published in Fire Technology *(DOI: 10.1007/s10694-025-01731-z)*

Hospitals present a distinctive evacuation challenge: many patients are dependent on staff, movement devices, and medical equipment to leave safely, so the time before anyone starts moving (the pre-movement phase) often governs the overall evacuation process [1]. This phase can include critical, but time-consuming, actions such as staff briefing, collecting portable equipment (e.g., portable oxygen), disconnecting patients from monitors, and arranging movement devices like beds or wheelchairs. Consequently, the delays associated with preparation frequently dominate the total evacuation time. In addition, because patients differ in mobility and level of assistance required, actual movement speeds can vary widely.

Although evacuation models are widely available and increasingly sophisticated, engineers still face challenges in populating these models with inputs for healthcare settings. In particular, valid values for pre-movement time and movement speeds are scarce, leaving practitioners to rely heavily on assumptions or data drawn from very different occupancies, such as offices or residential buildings. This limitation can lead to simulations that underestimate the evacuation time for hospitals, especially in high-acuity areas where patients have more complex medical needs.

Although research by Fahy and Proulx [2], Gwynne and Boyce [3], Geoerg et al. [4], and Lovreglio et al. [5] have provided valuable data on pre-movement time and movement speed, notable gaps remain in assisted-evacuation settings - particularly hospitals, healthcare facilities, and retirement homes - where the combination of patient vulnerability and reliance on staff makes evacuation uniquely challenging.

The aim of our study was to help close this gap by generating new, ward-specific data on both pre-movement and movement phases. Using real hospital evacuation drills conducted across multiple units in New Zealand, we systematically recorded and analysed preparation activities, device use, and evacuation movement speeds. By focusing on actual hospital staff operating in realistic clinical environments, our dataset provides insights that are directly transferable to practice. The intention is not only to enrich the academic understanding of hospital evacuation, but also to supply practitioners with data that they can use immediately when estimating realistic RSET inputs for performance-based design.

How we studied real evacuation drills

We analysed eight announced evacuation drills conducted across two hospitals in 2020, covering four representative clinical areas: a General Ward, a Hyper Acute Stroke Unit, a High Dependency Unit and a Post-Anaesthesia Care Unit. Drills involved simulated patients and on-duty staff, and were recorded with multiple fixed cameras. From the videos, we coded patient-level timelines with clear segmentation into:

1. Staff preparation (briefing or seeking further information);
2. Active preparation (such as movement device preparation and disconnection);
3. Passive preparation (waiting for staff or equipment); and
4. Movement.

The case mix spanned single-bed high-acuity rooms to multi-bed wards and recovery areas, with varying staff-to-patient ratios to reflect different clinical realities.

What we found

Pre-movement times - Across all eight drills, pre-movement was the dominant component of total evacuation time, with travel accounting for only about a quarter to a third of the overall time. The largest share of pre-movement was passive preparation (e.g., waiting for people, equipment, or clearances), while active preparation (e.g., device disconnection and patient set-up), and staff preparation formed the remainder. Averaged across settings, pre-movement was approximately 175 ± 107 seconds. Table 1 presents the experimental data by type of ward. Ward type was an important factor; wards with higher acuity patients had longer and more variable pre-movement times, despite higher staff-to-patient ratios, due to multiple devices requiring safe shutdown and disconnection. Apart from the High Dependency Unit, staff seldom worked strictly on one patient at a time, but instead they alternated between patients, creating staggered cycles of brief active tasks and passive waiting as they coordinated equipment and support.

Table 1 - Total pre-movement time [s] by type of ward

Type of ward	Number of patients observed	Mean [s]	SD [s]	Min [s]	Max [s]	Median [s]
General Ward	17	115.0	71.4	41.0	300.0	99.0
Hyper Acute Stroke Unit	10	172.8	94.2	36.0	314.0	185.5
High Dependency Unit	4	362.5	177.1	216.0	584.0	325.0
Post-Anaesthesia Care Unit	22	188.3	79.2	79.0	360.0	177.5

Evacuation movement speeds - Mode choice produced clear differences in horizontal movement speed. Patient evacuation by bed was the slowest, with mean speeds around 0.67 m/s, reflecting both the mechanical constraints of bed movement and the need for careful navigation. Wheelchair and walking evacuations were faster, averaging roughly 1.19 m/s and 1.07 m/s, respectively. Pooled across all evacuation modes, the mean horizontal speed was about 0.81 ± 0.40 m/s. Table 2 presents the movement speed results by ward type.

Table 2 - Movement speed [m/s] by type of occupancy

Type of ward	**Number of patients observed**	**Mean [m/s]**	**SD [m/s]**	**Min [m/s]**	**Max [m/s]**	**Median [m/s]**
General Ward	17	1.06	0.45	0.33	1.98	0.99
Hyper Acute Stroke Unit	10	0.95	0.26	0.53	1.40	0.97
High Dependency Unit	4	0.80	0.07	0.72	0.88	0.80
Post-Anaesthesia Care Unit	22	0.55	0.29	0.13	1.08	0.50

Why it matters for fire safety

The findings point to several actionable considerations for performance-based design in healthcare occupancies. Because passive preparation was often the single largest contributor to total evacuation time (Figure 1), the most impactful interventions are organisational: improving initial staff allocation, pre-staging essential transport equipment (such as wheelchairs and portable oxygen) and formalising early role assignments to reduce idle intervals. In high-acuity wards, like the High Dependency Unit, even generous staffing will not eliminate the time needed for safe device disconnection and patient preparation, which is labelled active preparation in this article. To shorten active preparation time, targeted training is important to ensure staff perform disconnection tasks as efficiently as possible.

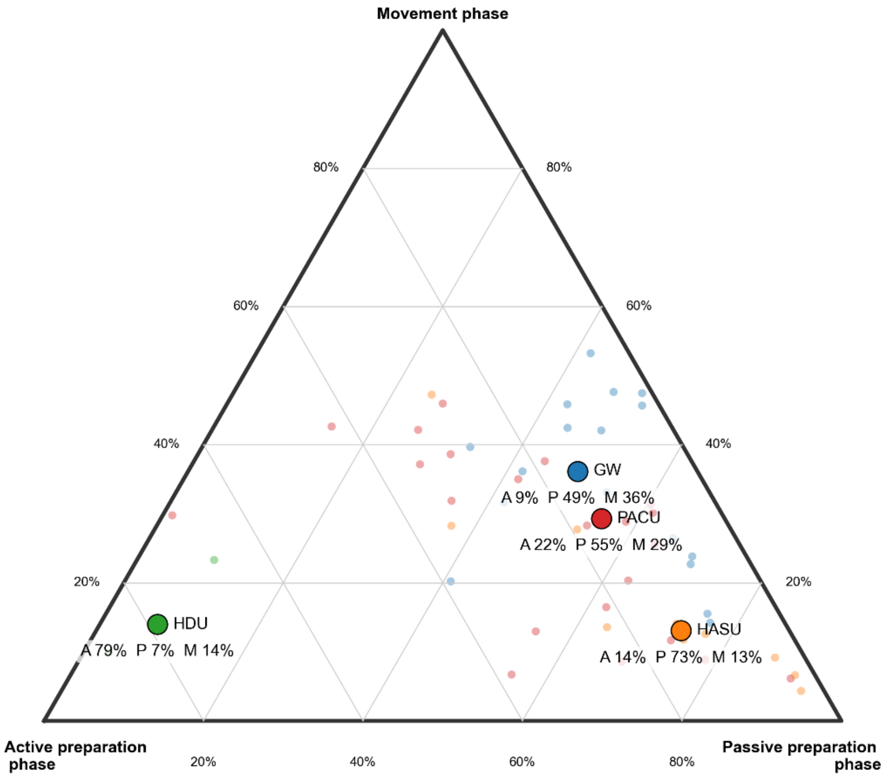

Figure 1: A ternary plot showing how evacuation time is divided into three phases: active preparation (staff actions such as disconnecting equipment), passive preparation (waiting or delays before movement), and movement (purposeful movement toward an exit). Each point represents data from an evacuation drill, with the larger symbols showing the median for each hospital ward type. The plot highlights how different wards face very different challenges: for example, patients in the High Dependency Unit spend most of their time in active preparation (79%), while those in the Hyper Acute Stroke Unit spend the majority in passive preparation (73%). By contrast, general ward evacuations show a more balanced mix across all three phases. Abbreviations: A: Active preparation phase, BP: Passive preparation phase, M: Movement phase, GW: General ward, HASU: Hyper Acute Stroke Unit, HDU: High Dependency Unit, PACU: Post-anaesthesia Care Unit.

When developing design scenarios it is important to consider pre-movement times which reflect the type of patient, their associated medical equipment, and their movement devices. Finally, egress modellers should consider the impact of concurrent patient preparation, rather than assuming purely sequential handling, as alternation is a common real-world strategy under resource constraints.

Although our data is collected in New Zealand, the procedures observed (staff preparation, active preparation, passive preparation, and movement) are common across healthcare systems worldwide. Absolute times will vary with staff-to-patient ratios, training, and resourcing, but the overall finding - that pre-movement phases are significant and can dominate evacuation timing - is broadly transferable.

Conclusion

In hospital evacuations, pre-movement time typically dominates over movement time. Pre-movement time can be broken into multiple phases, such as staff preparation time, passive preparation time (waiting), and active preparation time (purposeful work to get a patient ready to evacuate). This distinction between passive and active preparation helps clarify where evacuation times can be reduced, as well as making sure the phases of real evacuation in hospitals are captured. Passive preparation is often far longer than the active preparation, except in High Dependency Units that have high staff-to-patient ratios.

Egress modelling inputs must account for both passive and active preparation times, and these values should be adjusted according to the patient acuity (e.g., acknowledging that High Dependency Unit patients need much longer time to prepare due to their more complex medical equipment).

Overall, this research highlights the sub-components that make up the pre-movement time in hospital evacuation. While this dataset provides useful input for egress modelling, it also lays the foundation for further work to better understand of the factors influencing active preparation, such as the time to disconnect specific types of medical equipment.

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