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Principles for the fire performance of external wall systems

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Abstract. Recent high-profile fires involving combustible façades have exposed significant gaps in both the understanding and regulation of external wall systems. Modern façade designs frequently employ polymers as insulation and/or laminated composite materials that, while improving energy efficiency, can inadvertently create pathways for vertical fire spread. Thus, there is a need to establish fundamental principles for evaluating the fire spread performance of these systems. Drawing on notable incidents, it is shown how uncontrolled flame spread can defeat compartmentation strategies, compromise occupant egress, and overwhelm firefighting efforts. Extending on previous studies, a performance-based approach to fire spread is proposed, examining four levels of relevance: material properties, product characteristics, assembly configuration, and overall building context. Key factors include combustibility, ventilation effects, and real-world variables (e.g., building characteristics). Case studies of testing methods illustrate both utility and limitations in capturing metrics relevant to façade design. Ultimately, it is advocated that there is an urgent need for rigorous, tailored assessment protocols supported by professional competence, thereby ensuring that complex external wall systems can be designed and managed to balance fire safety with sustainability and safety objectives.

1. Introduction and Background

Ensuring fire safety in buildings has always been a cornerstone in the development of the built environment. In this, fire compartmentation, which aims to control fire growth and spread between compartments, represents a key aspect of the fire safety strategy put in place to safeguard occupants and reduce the consequences of fires. This is typically achieved through a certain fire resistance rating (integrity and insulation, and at times load-bearing capacity) of building elements such as walls, floors, and doors.

Adding to this, strict combustibility restrictions have historically been imposed on the external wall systems of buildings, particularly tall buildings. However, sustainability-driven policies promoting lightweight façades and improved thermal performance have accelerated the use of combustible façade components. This shift has outpaced regulatory adaptation, leaving significant gaps in performance assessment [1]. More specifically, these combustible materials, such as thermal insulation or various composite products, enhance visual, thermal, acoustic, and durability performance, but they challenge the fire safety-related functionality that a building envelope needs to fulfil [2]. This trend has introduced considerable complexity from a fire safety perspective, as façades can inadvertently create pathways for vertical fire spread if not properly designed and evaluated [3].

Several large fire incidents have highlighted these risks, and the Grenfell Tower fire (London, 2017) is the most studied of these fire tragedies. In this building, the fire spread externally via a wall system formed of aluminium composite panels (ACPs) with a polyethylene core and combustible insulation, leading to 72 fatalities [4]. Similarly, the Shanghai High-Rise fire (China, 2010) saw rapid vertical flame propagation due to polyurethane-based insulation, resulting in 58 deaths [5]. Other incidents, such as the Lacrosse fire (Melbourne, 2014) and the Address Downtown fire (Dubai, 2015), did not result in fatalities but further demonstrated how combustible cladding can drive fire spread, thereby causing unacceptable property damage and economic loss [3]. These and many other cases highlight how façade design can compromise compartmentation, hindering egress, and overwhelming firefighting efforts, particularly in high-rise structures [6].

Despite the efforts to better understand the fire performance of façade systems, it is still not clear whether the tools needed for these assessments are adequate. Attempts to develop new testing methodologies remain inscribed within the same frameworks, developed two or more decades ago, although these frameworks have been deemed inadequate by the Grenfell Tower Inquiry [4]. Alternatively, more rigorous approaches like the University of Queensland (Australia) Cladding Materials Library (CML) [3, 7] follow a more fundamental path but, nevertheless, remain incomplete.

The following outlines some fundamental principles for evaluating the fire performance of external wall systems. Centred on fire safety strategies, expected performance, performance quantification, and testing practices, it aims to demonstrate how a robust, performance-based approach can mitigate risks and enhance confidence in façade design. By reviewing fire safety considerations at the material, product, assembly, and building levels, it is highlighted how systematically defined performance objectives, aligned with the building's overall fire safety strategy, can ensure safer and more effective façade design [8].

2. Fire safety strategies and expected performance

The choice of a fire safety strategy in a building is determined by multiple factors, including its function and importance (e.g., buildings with critical roles like hospitals), the occupant risk profile (e.g., awake or asleep, self-reliant or dependent), building height, and other key considerations. An appropriate evacuation strategy is selected as part of the fire safety plan, such as phased evacuation, a "stay-put" approach, or simultaneous evacuation. For example, high-rise buildings with vulnerable occupants, such as hospitals and care homes, may rely on "defend in place" or "stay-put" strategies, while office towers or hotels may adopt total (all-out) or phased evacuation [5].

As the external wall systems can influence the fire safety strategy, different strategies should impose different demands on the fire performance of the wall system. The first step is to identify the performance criteria that align with the building's objectives. For instance, in a high-rise building, a fundamental performance criterion is the absence, or the extent, of vertical fire spread. As illustrated in Figure 1, three scenarios can typically arise. In the absence of vertical fire spread (a), where the façade prevents fire from spreading to adjacent compartments (both horizontally and vertically), a "stay-put" evacuation strategy can be implemented. In contrast, if a façade system allows smoke or fire to migrate to adjacent compartments, then the "stay-put" strategy becomes unviable. In the case of a breach of vertical compartmentation, a phased evacuation may be preferred if limited vertical fire spread can be ensured (b). Finally, if the external wall system can promote significant fire spread (c), a total (all-out) evacuation strategy should be applied. In any case, predicting the potential nature of external fire spread is critical to establish if the façade design supports the chosen fire safety strategy [6]. In a sense, the last scenario could be seen as analogous to a fire spreading from an atrium, and as such, it is evident that immediate evacuation is recommended. In addition, when phased or total evacuation is part of the fire safety strategy, it becomes fundamental to ensure that the evacuation route is not exposed to burning/falling debris.

In conclusion, establishing clear performance criteria for external wall systems is essential for ensuring an appropriate fire safety strategy. Thus, a façade assembly that passes a standard fire test based on a pass/fail criterion may still fail to meet the specific performance requirements of a given building unless the test conditions and acceptance parameters closely reflect that building's characteristics and its fire safety strategy [3]. Unfortunately, such considerations are currently not required, and the testing is thus disconnected from the overall performance goals with respect to fire safety [9]. Moreover, the pass/fail approval scheme for façades creates an even greater disconnect with the performance objectives of the building, as the focus gets shifted to optimising for passing the test rather than to ensuring fire safety.

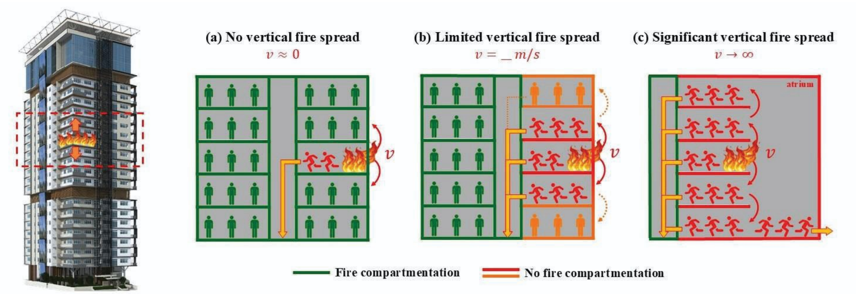

Figure 1. Example of the relationship between different vertical fire spreads through the external wall system and evacuation strategies, within the context of a fire safety strategy.

3. Performance quantification

Based on the above, a fundamental question arises when trying to establish a fire safety strategy in a multi-story building: what information is needed to ensure that an external wall system ensures fire safety? As presented in the Cladding Materials Library (CML) [3, 7], a performance-based framework relies on quantifiable parameters across four distinct levels that should form the starting point for a fire safety strategy: material, product, system (assembly), and building. Figure 2 recaps the in-depth overview given in the CML, which also offers rich discussion and several contextual examples.

In short, the goal is to achieve fire safety strategy alignment. In this context, that means that it is necessary to ensure compatibility with building-specific fire safety measures, considering height, occupant density, evacuation strategy, active protection systems, and firefighting access.

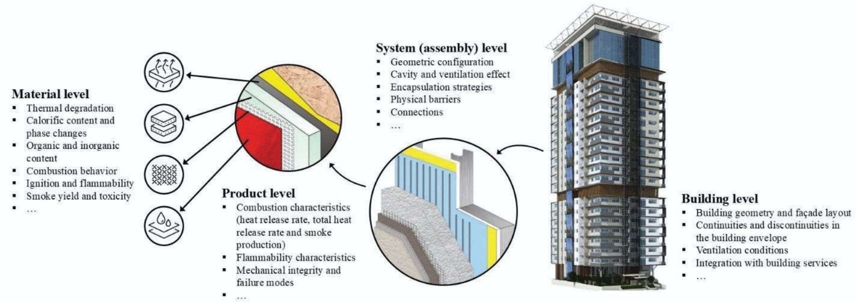

Figure 2. By assessing external wall systems across the four levels given in the Cladding Materials Library (CML) **-** material, product, assembly, and building **-** their fire performance can be effectively quantified and aligned with broader fire safety objectives.

4. Performance and fire testing

Ideally, façade fire tests should measure the performance parameters identified above, like flame spread rate or structural failure modes [3, 4]. Unfortunately, many standardised tests yield a simplistic outcome that may overlook system nuances. For example, the BS 8414 Series (UK) and NFPA 285 (USA) only measure temperature at specific heights [10, 11]. Although the information extracted from these tests is potentially useful, it is incomplete, and rarely, if at all, used for design purposes. These tests are poorly instrumented, and information collection is very limited. Similarly, the SP Fire 105 test from Sweden uses a three-story rig to observe flame spread, yet it also suffers from limited instrumentation or insufficient coverage to capture all relevant performance data [10]. In addition, while the ISO 13785 series attempts to standardise façade testing internationally, the testing regimes remain of weak relevance and significant differences persist in the acceptance criteria across countries [11].

A rather worrying part, however, is that scenario-based tests, such as these large-scale tests, do not focus on providing appropriate data for engineers to make an adequate assessment of the capabilities of a façade system. Instead, they erroneously focus on trying to replicate reality, and, unfortunately, a common misunderstanding is that passing a test ensures fire safety, when it, in fact, only has given an indication of relative performance in an isolated scenario that has been established primarily to ensure harmonised construction product regulations. In fact, standard façade fire tests normally cannot replicate all possible building shapes and/or ventilation conditions. Consequently, the performance in a large-scale test may be different from many real fire scenarios [12] – in fact, it is expected to be. Furthermore, while certain test and assessment standards such as BS 8414 and BR 135 do not provide a pass/fail criterion, but are instead requiring an engineering analysis, they fail deliver the information for adequate support of such an approach.

Due to the high cost of large-scale façade tests, the use of smaller test setups is a typical path to consider, like the introduction of the SBI instead of the room corner test. One example of this is that the authorities in the Netherlands have suggested using the ISO 13785 mid-scale test for assessment [13] – both due to costs and because they cannot wait for the European façade test standard to be approved. Unfortunately, such downscaling provides an even greater disconnect with the fire safety strategy, as it excludes elements of the system-level needs outlined in the CML approach, as well as fully excludes the building-level aspects. Figure 3 illustrates how downscaling a façade fire test further and further removes the outcome from the objective of supporting a fire safety strategy with comprehensive and robust data.

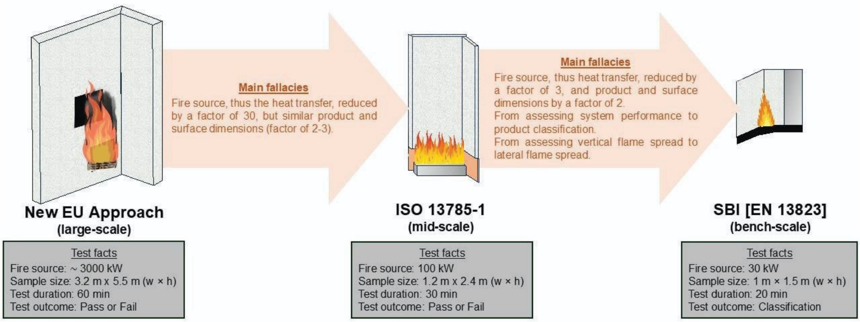

Figure 3. Example of scaling fallacies in fire testing: main fallacies for downscaling and test facts for the new European approach to assess the fire performance of façades (large-scale), the ISO intermediate-scale test for façades (mid-scale), and the Single Burning Item (SBI) test (bench-scale).

In terms of scaling down tests, a critical illustration of test limitations is found in the suggested use of the Single Burning Item (SBI) test for façade test purposes. Although intended and widely adopted for reaction-to-fire classification of internal linings (i.e., walls and ceilings), the Euroclass classification based on SBI tests is fundamentally limited for façade assessments. As discussed by Messerschmidt (2008) [14], the SBI test primarily measures a material's propensity to flashover rather than quantifying lateral fire spread. Furthermore, its configuration results in lateral flame spread being emphasised, hence using SBI test data for façade performance assessment is extremely complex, if not impossible (at least as a standalone method). Furthermore, using the SBI classification scheme is simply incorrect.

The SBI example supports the idea that, given the current testing regimes, the challenge is not in defining performance quantities or selecting a test scale, but rather in ensuring that highly competent professionals are available to define an appropriate suite of tests and interpret the data in the context of each building's unique requirements. It is the expertise and judgment of the professional overseeing the assessment that contextualises test data for the specific building and ultimately decides whether the façade system performs safely. Additionally, scaling these tests to account for real building heights or floor layouts remains problematic as many test rigs only capture up to two or three stories, hence all the relevant phenomena might not be fully characterised [8].

A more refined strategy must couple robust material and product-level testing with advanced modelling of the full assembly and the building. The concept of "scaling-up fire" ties together fundamental sub-processes, like pyrolysis, flame spread, and mechanical failure, into a comprehensive model that acknowledges uncertainty [8]. Such a framework should be capable of integrating building-specific features such as large openings, balconies, and corner details, while also evaluating partial failures or sequence-based events like repeated window breakage. Ultimately, the goal is to reduce reliance on coarse pass/fail tests by generating measurable performance data and linking that data to the actual building's fire safety strategy [3].

5. Conclusions

Modern façade fires have exposed significant gaps in traditional, prescriptive fire safety methods. The continuous push for innovative materials and energy-efficient solutions calls for strategies that are equally robust and forward-looking. Fire safety objectives must explicitly guide the façade's required performance. Material- and product-level flammability data alone are insufficient unless evaluated in realistic configurations that account for ventilation, mechanical failure, and interactions with building geometry. Although large-scale tests such as BS 8414 and SP Fire 105, as well as the newly proposed European standard [10-12], can provide useful data, they should be augmented by proper instrumentation so that performance-based criteria, advanced reasoning, can be used to address specific building needs. A shift toward performance-based approaches is therefore essential for external wall systems. By systematically integrating building-specific fire strategies, measurable performance metrics, and rigorous testing protocols, stakeholders can address the inherent risks of modern façade design while maintaining sustainability and aesthetic goals.

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