Fire Safety of Timber Buildings – The Case of Photovoltaic Systems

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Photovoltaic (PV) systems play an important role in reducing society's dependence on carbon-based energy sources, and their coupling with timber buildings is an interesting and expected solution for meeting sustainability requirements in the modern built environment. However, both PV systems and timber structures have unique fire safety challenges, and their combination may introduce additional risks. Therefore, relevant fire hazards associated with each of the technologies and their pairing are discussed. The findings highlight the importance of revising fire testing standards and developing tailored safety measures to identify and manage these risks.

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Introduction

The use of timber in construction has evolved rapidly in the past decades, especially with the increased use of engineered wood products such as glulam and cross-laminated timber (CLT). Timber is renewable, recyclable, reusable, and offers a lower carbon footprint than most traditional construction materials (Buchanan and Levine 1999). In addition to other advantages related to construction, such as a high level of prefabrication and easy handling during assembly (Wade 2019), these environmental aspects have introduced timber as an important pathway for reducing the environmental impact in the construction sector. However, for that to be a reality, fire safety challenges associated with timber buildings must be addressed (Hamzi *et al.* 2008).

To further enhance the sustainability rating, alternative energy sources can be implemented in timber buildings. This includes the use of solar energy through photovoltaic (PV) systems, which is a relatively inexpensive and reliable source of renewable energy (Ram *et al.* 2018). However, research has shown that PV systems introduce fire hazards that must be recognized and addressed to prevent substantial negative consequences and maintain their sustainability contribution (Mohd Nizam Ong *et al.* 2022).

Given their individual complexities and fire safety challenges, combining timber construction with PV systems poses a novel fire safety engineering challenge that is essential to tackle. The following provides insights into some of these challenges and related implications for the fire safety engineering discipline.

Fire Safety Challenges of PV Systems

Currently, the most common types of PV systems in the construction sector are rigid PV modules that are installed as Building-Applied PV (BAPV) systems or Building-Integrated PV (BIPV) systems. When PV modules replace conventional building materials/components, replacing their functions, they are considered BIPV. Otherwise, when they are just added to an existing building, they are considered BAPV (Singh *et al.* 2021). Since BIPV systems are integral part of the building, they are considered construction products and thus are subject to the construction product regulations (CPR) (Eur. Parliament Reg. 305/2011). BAPV systems, however, are not part of the building structure. Therefore, CPR requirements are not relevant for BAPV systems, leaving some discrepancies in addressing fire safety between BIPV and BAPV installations. Nonetheless, both BAPV and BIPV systems increase the fire risk through increased frequency (Aram *et al.* 2021) and consequence (Kristensen *et al.* 2021) of fires.

Direct contact of the PV assembly with the timber structure does not result in immediate fire-related issues because mass timber does not ignite that easily. However, when PV systems are installed, there are invariably membranes, vapour barriers, or combustible insulation materials in proximity, which allows for a fire to start and spread more easily over a large area. On flat roofs, the mechanism of the PV system's influence can be summarised as an enhanced heat-feedback loop. PV panels reflect radiant heat coming from the flames back towards the roof surface, thus heating it in an intensified manner. This overcomes the inherent safety characteristics of membranes, which typically prevent fire to spread across the roof surface below the modules (Kristensen *et al.* 2021).

Different parts of the PV system are subject to some performance requirements (IEC 61730-1 & 2, 2023), but they focus on hazards at the material and product level. The hazards that emerge on the system level have not been sufficiently recognized and considered (Faudzi 2019; Kristensen *et al.* 2021). On the roof, for instance, one of the main concerns when assessing fire safety at the system level is that a PV system can override the safety measures required for roofs, *i.e.*, the requirement for the roof membrane not to allow flame spread across its surface (EN 13501-5).

Furthermore, the PV system on the roof creates a semi-enclosed space below the PV modules. This space between the PV module and the roof membrane can facilitate the flame spread beyond the area of the ignition source *via* the altered mechanism of fire dynamics (Kristensen *et al.* 2021). The cavity enables higher heat feedback to the location of combustion and increases the preheating rate of the surrounding material, enabling (i) higher flame spread rate and (ii) fire to spread to a larger area. Roof materials, PV modules, and the geometry between them create specific hazards that do not emerge if only separate parts of the system are assessed; thus, the risk of the whole system must be considered (Jomaas *et al.* 2024).

Implementation of PV systems in façades (*i.e.*, BIPV systems) faces two main challenges. Firstly, researchers have expressed concerns regarding the falling objects caused by a BIPV façade fire (Stølen *et al.* 2023), where PV modules came flying off during a fire test. The second one is the extent of the vertical flame propagation through the building envelope (Livkiss *et al.* 2018) that can occur in the cavity behind the PV module.

PV Systems on Timber Buildings

Combining the PV system with timber building brings together the already-known hazards of both technologies, as well as new ones that could arise from the merger of the two. The three main pathways for fire spread are: 1) from the inside of the building spreading to the building envelope; 2) from outside of- the building spreading into the building; 3) from inside a building spreading to another part of the building through the façade or roof. The presence and characteristics of PV systems significantly affect all these fire cases, which can facilitate ignition and/or flame spread.

On the other hand, when timber in a compartment is left exposed, its combustion notably influences fire development (Hadden *et al.* 2017). Exposed timber can increase fire severity, producing larger flames and smoke plumes from compartment openings, which may exert an increased fire load on the façade, where BIPV could be installed (Gorska *et al.* 2017). This intensified fire load could undermine existing safety features on building façades, like spandrels or horizontal projections, which are not designed to contain fires of this magnitude (Oleskiewicz 1991).

The existing fire safety measures prescribed and required by the legislation are typically developed and scaled for non-combustible construction materials, which represent traditional construction. The above implications result in an increased risk for the fire to spread across the building envelope (vertically and/or laterally) and, consequently, an overall increased fire risk. Indeed, these outcomes challenge many of the usual assumptions adopted in fire safety engineering to develop a fire safety strategy, like a single-compartment fire and the absence of fire spread between compartments.

Outlook

Both timber and PV systems offer significant environmental benefits, where timber reduces the carbon footprint of buildings and solar power provides affordable and renewable energy. However, their combined use can introduce novel fire safety challenges that should be properly addressed to ensure robust solutions for fire-safe and sustainable buildings in the future. Exposed timber in compartments increases the fuel load and fire severity. Simultaneously, PV systems raise the probability of ignition and can lead to more severe fire consequences. Addressing these combined risks requires comprehensive research and competent professionals to develop effective fire safety measures. Moving forward, it is essential to establish testing methods and regulatory frameworks that can specifically address the fire risks posed by these combined technologies. A proactive approach to fire safety will be necessary to ensure that timber and PV systems contribute to a greener future without compromising safety.

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