Study Report

SR468 [2022]

Fire performance of structural insulated panels (SIPs) for residential buildings – a review of literature

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Funded from the
Building Research Levy

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ISSN: 1179-6197

Preface

This report is one of three published as part of the BRANZ research project *Structural insulated panels (SIPs) – durability, seismic and fire performance*.

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Reference

Walsh, A., Carradine, D., Li, K., Frank, K. & Hare, G. (2022). *Fire performance of structural insulated panels (SIPs) for residential buildings – a review of literature*. BRANZ Study Report SR468. Judgeford, New Zealand: BRANZ Ltd.

Abstract

Construction using structural insulated panels (SIPs) has been suggested as one possible solution to New Zealand's urgent need for fast, affordable and quality homes. SIPs for residential construction have a relatively short history of use in New Zealand, and therefore little information is available about their performance in a local context. This report has considered the fire performance of SIPs based on overseas and New Zealand literature at both a material and building level. This report highlights that SIPs can be manufactured with a range of materials for both the core and face-layer components and that the choice of materials can influence the behaviour of the system in reaction to fire. Similarly, SIP systems can be configured using different connections and assembly methods, which can also affect fire performance of the buildings using them. SIPs with timber-based face layers are used most commonly internationally for residential construction, and considerable work has been done overseas to investigate and manage their fire safety. In countries where SIPs have been used for several decades, guidance documents have been developed that suggest SIP buildings can meet fire safety regulatory requirements with the use of suitable lining materials, where specific fire resistance ratings are specified. The inclusion of SIPs in some building codes further indicates confidence in their use in those jurisdictions. Much of the overseas information and documentation is relevant to the New Zealand setting, although some specific tests are likely to be required to ensure systems comply with local regulations. The type of building will determine what fire performance requirements apply. Different fire safety requirements will apply for various SIP building components depending on the building typology, usage and occupancy.

Keywords

Structural insulated panels, SIPs, fire, sandwich panel.

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Executive summary

Construction using structural insulated panels (SIPs) has been suggested as one possible solution to New Zealand's urgent need for fast, affordable and quality homes. Although they have been used in some countries for several decades, SIPs for residential construction have a relatively short history of use in New Zealand, and therefore little information is available about their performance in a local context. This report has considered the fire performance of SIPs based on overseas and New Zealand literature at both a material and building level to understand their behaviour and suitability for use within the local compliance regulations.

This literature review presents observations and findings from overseas and New Zealand literature to understand how SIPs perform in fire scenarios. The main focus of this review has been on SIPs systems used for residential construction, although learnings from commercial applications have been included as relevant. In addition, the work has considered fire safety regulations in a selection of countries and how compliance of SIPs buildings is managed in those jurisdictions, including New Zealand.

The report highlights that SIPs can be manufactured with a range of materials for both the core and face-layer components and that the choice of materials can influence the fire resistance of the system and its behaviour in reaction to fire. Similarly, SIP systems can be configured using different connections and assembly methods, which can also affect the fire performance of the buildings using them. SIPs with timber-based face layers are used most commonly internationally for residential construction, and considerable work has been done overseas to investigate and manage their fire safety. In countries where SIPs have been used for several decades, guidance documents have been developed that suggest SIP buildings can meet fire safety regulatory requirements with the use of suitable lining materials, where specific fire resistance ratings are specified. The inclusion of SIPs in some building codes further indicates confidence in their use in those jurisdictions.

Much of the overseas information and documentation is relevant to the New Zealand setting, although some specific tests are likely to be required to ensure that systems comply with local regulations. The type of building will determine what fire performance requirements apply. In New Zealand, there are no specific fire performance requirements that would affect the use of typical residential-style SIPs in low-rise, stand-alone residential buildings. For higher-risk building use types, fire safety requirements will apply for different building components depending on the building typology, usage and occupancy.

1. Introduction

New Zealand has an urgent need for quality housing that can be built quickly and affordably. Construction using structural insulated panels (SIPs) has been suggested as one possible solution. SIPs are sandwich panels made of two face layers and an insulating inner core, which can be prefabricated and assembled quickly on site and could be used to increase construction speed and reduce overall building cost. While SIPs have been used extensively overseas for several decades, less is known about their performance in a New Zealand context.

SIPs have been a common element in commercial cold store building applications for several decades in many countries. Metal face layers are typically used for SIPs in commercial applications. SIPs have gained popularity more recently for residential construction, particularly in North America and parts of Europe as well as New Zealand. The growing popularity of SIPs is recognised by the establishment of trade associations, including UKSIPS (now merged with the Structural Timber Association) and the US-based Structural Insulated Panel Association (SIPA).

SIPs having wood-based panels as the outer face layers have been used for residential construction in North America since the early 1990s and have also proven effective in other seismically active parts of the world including Japan (Yeh, Williamson & Keith, 2008). The growth in SIP usage in North America resulted in increased research and documentation on the design and detailing of SIP structures. These activities have culminated in a joint standard between the American National Standards Institute (ANSI) and APA – The Engineered Wood Association, ANSI/APA PRS 610.1 *Standard for performance-rated structural insulated panels in wall applications*, which provides requirements and test methods for qualification of SIPs for use within building standards such as the International Residential Code (IRC).[1] APA has also published a SIPs product guide (APA, 2018) that contains practical information on the environmental and economic benefits of SIPs and also includes span tables, standard details and a brief discussion on achieving code-compliant fire resistance for residential and commercial buildings using SIPs. SIPA is a US-based association dedicated to educating and informing designers, builders and building owners about the benefits and appropriate methods for designing and building with SIPs. SIPA has published a number of documents aiming to fulfil these objectives and has also contributed to the previously mentioned documents from APA. This documentation and inclusions of SIPs suggest that these systems will perform adequately under all required loading scenarios, but these are specific to North America.

There also exist numerous international standards for the testing and performance of SIPs for use as building components. The International Code Council Evaluation Service (ICC-ES) provides testing and validation procedures for recognising the use of SIPs within the International Building Code (IBC)[2] and the IRC through the use of ICC-ES AC04 *Acceptance criteria for sandwich panels*. This document includes necessary structural and durability test standards and performance targets that must be met and does include some requirements for the fire performance of the face layers, core material and adhesives when used. ICC-ES AC05 *Acceptance criteria for sandwich panel adhesives* provides more-specific test methods for evaluating adhesives when used for bonding the face layers to the core materials. Other standards and test

[1] https://codes.iccsafe.org/content/IRC2021P2
[2] https://codes.iccsafe.org/content/IBC2021P2

methods exist for evaluating a range of structural and durability properties of SIPs, and these are discussed in more detail in the respective workstream reports for this project.

In addition to the available test methods and standards for SIPs, design guidance and information on the systems are provided by several organisations internationally, including the Structural Timber Association and the Timber Research and Development Association in the UK and Wood Solutions in Australia. These organisations provide independent non-proprietary information about wood products to the building industry.

The collection of standards and design guidance on SIPs internationally is a clear indication that this type of building is being taken seriously and used to some extent in developed countries around the world, even though we have yet to see this system within the currently existing New Zealand codes and standards.

SIPs building systems are different to New Zealand's traditional light timber-framed construction in the way they are constructed, the materials involved and the performance of the completed building. As with other construction systems, SIP structures need to demonstrate compliance with the relevant fire performance requirements in clause C *Protection from fire* of the New Zealand Building Code, which vary depending on the specific application. It is therefore important to consider the fire performance within the New Zealand context to ensure the behaviour of these systems is understood, trusted because findings are backed by evidence and will be suitable for use within the local compliance regulations.

The fire performance of building systems is typically considered in terms of how they behave during the main stages of a fire: (1) ignition and fire growth and (2) fully developed fire. During the first stage, the reaction-to-fire system characteristics are considered, including factors such as ignitability, heat release rate and smoke production. At this stage, the propensity for fire to spread over the system is the primary consideration, although mechanical performance and tenability affects may also be considered. During a fully developed fire, the fire resistance of the system – the extent to which the system will prevent the spread of fire to other fire compartments and/or continue to meet structural adequacy requirements – is the primary consideration. Increasingly, the contributions of combustible system components to the fuel load that may prolong the fire exposure are also considered.

As noted above, there is an ample amount of international documentation and information for the design and evaluation of SIP products and systems. There are currently no direct references to SIPs in New Zealand building codes or standards. However, there is consideration of systems including foamed plastics that would apply to some SIPs. A report on the seismic performance of SIPs in the New Zealand context based on BRANZ research is available (Carradine, 2021). The purpose of this report is to reflect on current knowledge about the fire performance of SIPs in residential applications based on the available literature from overseas and New Zealand sources. International research and literature have been considered in relation to New Zealand building practices and regulatory requirements. This review also identifies knowledge gaps where further research may be beneficial to support the acceptance of SIPs in New Zealand. This report is one output of a BRANZ project investigating the durability, seismic performance and fire performance of SIPs for suitability in use in New Zealand residential buildings.

2. SIP components

A typical SIP has two outer face layers with an insulating inner core between them. SIP face layers are typically either engineered wood panels, cement-based panels or metal sheets. Core materials are commonly expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PUR) or polyisocyanurate (PIR) rigid foams, although fibrous insulation products such as mineral wool can also be used. The core layer is bonded to the face layers by an adhesive or by self-adhesion. Internationally, there are some examples of alternative face and core layers, including a range of bio-based panel and insulation materials (McIntosh & Harrington, 2007; Kojima et al., 2021), although these appear to be uncommon in the current SIPs market in New Zealand.

SIPs-based building systems include interconnected components that are used as structural wall, roof and floor elements. When required by the application, the complete system must fulfil requirements for fire resistance or reaction to fire as dictated by the New Zealand Building Code. An understanding of how individual components react to fire and elevated heat conditions can provide insight on how the installed systems will perform in fire conditions. The face layers are the primary load-carrying components of SIPs, but the core and adhesion of the face layers to the core provide stability to the face layers and are integral to the fire and structural performance of SIP buildings. Combustible foamed insulation products used as the core are often the SIP component most susceptible to heat degradation and the most reactive to fire. The following sections will discuss the component materials of SIPs with consideration of their contributions to the fire performance of SIP systems.

2.1 Face layers

2.1.1 Timbers

According to SIPA, 94% of SIPs used in North America for residential construction are made using oriented strand board (OSB) of nominal thickness of 12 mm. OSB is a multi-layered engineered wood board made from strands of wood, adhered together with a binder, where strands are layered and aligned in a specific orientation. Examples of other engineered wood products used as SIP face layers are particleboard, plywood and other reconstituted wood panels. Engineered wood panel products generally consist of timber components bonded together with an adhesive or resin binder between veneers (in the case of plywood) or to bind timber strands or particles together (in the case of OSB or reconstituted wood panels).

There are several SIP suppliers in New Zealand who either manufacture SIPs locally, import them from overseas or assemble them in New Zealand using overseas components. In New Zealand residential construction, SIPs with timber-based skins appear to be most prevalent. The timber-based boards are typically either an imported OSB or a locally manufactured reconstituted wood panel.

OSB panels from North America have been the most widely used overseas facing for SIPs in New Zealand and are manufactured to specific standards for performance and certified so that consistent and reliable products are available. In the United States, OSB is manufactured according to the USDOC Voluntary Product Standard PS 2-18 *Performance standard for wood structural panels* with certification provided by agencies such as APA – The Engineered Wood Association. Canada manufactures OSB according to CAN/CSA-0325 *Construction sheathing*, which is an adaptation of PS 2-18 with some minor modifications. Products manufactured and certified to these standards are accepted by US and Canadian building codes as acceptable materials for construction. These product standards include a range of performance criteria and testing methods but have no requirements around the fire resistance of OSB. Fire performance requirements of OSB and similar panels, when used as part of structural systems, are described in North American building codes such as the IBC and the IRC. According to ICC-ES AC04, which includes provisions for the use primarily of OSB-skinned SIPs, the panels must fulfil criteria relating to flame spread and smoke density when the outer faces are exposed. Testing can be required when these properties are affected by the core material of the panel.

Timber-based panels char in response to heat and flame. When exposed to heat, minor surface cracks are closed by the expanding char layer, which reduces the heat exposure deeper into the panel. With ongoing exposure, the char layer is impaired by deep fissures, which expose the core layer and trigger accelerated decomposition of the loadbearing system. Timber-based panels represent a fire hazard prior to through-depth board failure since their surfaces ignite and spread flame. Therefore, SIPs with timber-based facings are often encapsulated with plasterboard but not always. This is not the case with the mineral-based boards, which do not ignite or release substantial heat in the first stages of the exposure (Bregulla, 2003).

Wood strands in OSB are bound by an adhesive such as urea-formaldehyde or melamine resin (Yang, 2016). When urea-formaldehyde resin is heated above 176°C, it begins to decompose and releases formaldehyde. At temperatures above 200°C, urea-formaldehyde can produce pyrolysis products such as carbon monoxide, carbon dioxide, ammonia, cyanide and acetaldehyde. These are irritating or suffocating gases, and the pyrolysis gas is more toxic than when each component exists alone (Zhang et al. 1993).

OSB is a combustible material that can be covered by a non-combustible lining such as gypsum plasterboard to prevent flame spread across its surface. A crucial issue in the selection of face-layer material is weight. The insulating cores are very light, and for construction purposes, it is ideal for the whole panel to not be too heavy. When choosing timber-based materials, a reasonable balance must be achieved between fire protection, structural performance and total weight (Bregulla, 2003). In that respect, SIPs clad with timber-based panels and plasterboard linings are efficient because they combine low density and excellent structural performance and can have increased fire performance due to encapsulation by the plasterboard. Laboratory tests conducted on individual SIP panels with OSB face layers indicated that using a 15 mm or 30 mm fire-rated plasterboard for applications where a 30-minute or 60-minute fire resistance respectively was required was sufficient to adequately limit the temperature rise of the core (Lennon & Hopkin, 2010).

Ozkaya et al. (2006) studied the effect of fire retardants (potassium carbonate, borax and wolmanit) on the burning characteristics of OSB. A total of 56 samples were prepared in accordance with DIN-4102 *Fire behaviour of building materials and elements* and subjected to a burning test. According to the statistical analyses obtained as the result of the tests, potassium carbonate was determined to be the most suitable substance for improving the burning characteristics of OSB among those tested. This was because it had the longest ignition time and the shortest periods of burning with flames and as embers, along with borax, after the flames were turned off. It was also found that the most suitable method of applying the chemical substances to the surface was dipping. Yang (2016) introduced the technologies of preparing flame-retardant OSB in the US, such as basic borate, guanidine compounds and foaming fireproof coatings, which provided reference for the technological innovation of flame-retardant OSB production in other countries. However, for SIPs whose outer board is OSB, the most commonly used method to enhance its flame-retardant performance is to include gypsum plasterboard linings. Qu et al. (2019) compared the combustion performance of OSB and ecological board. Compared with directional particleboard and ecological board, the flame-retardant ecological board was able to effectively reduce the heat release rate and total heat release of the wall, reduce the building fire load and spread rate and improve the fire performance.

Reconstituted wood panels used for some New Zealand-manufactured SIPs are similar in fire performance to OSB and would therefore provide an acceptable facing for SIPs. Manufacturers would need to provide evidence of this performance depending on the building application. As noted above, there are potential options for enhancing the fire performance of these panel products, but it is not currently known if this is being included within panels being used for SIPs in New Zealand. Plasterboard encapsulation would reduce the need for increased fire performance in most instances. It has also been demonstrated that the inclusion of battens between the plasterboard and timber-based skins can reduce heat transfer and provide acceptable fire resistance ratings for these SIPs (Lennon & Hopkin, 2010).

2.1.2 Metal

Metal-based SIPs typically use lightweight steel or aluminium as the face-layer material with either an EPS or PUR core. The metal sheets are often corrugated to different extents to provide additional strength and stiffness to the panels. The fire performance of metal-based SIPs has been well studied in relation to their common use in industrial and commercial applications – for example, in cold storage facilities and as external cladding layers (Baker, 2002; Collier & Baker 2004; Guinta d'Albani, 2014). Feedback from industry practitioners suggests that metal-skinned SIPs are being increasingly used in residential construction in New Zealand. The advantages reported are that metal-skinned SIPs are readily available, easy to handle and can quickly form a completed building envelope without the need for additional internal or external lining.

Unlike timber-based face layers that char during fire and heat exposure, metal-skinned panels quickly conduct heat to the core and interface between the face and core, resulting in possible panel delamination and softening of the metal skins. These mechanisms can result in rapid strength and stiffness loss once the panels reach a certain temperature. Research on non-structural metal-skinned insulated panels, very similar to those used as SIPs, has indicated that the detailing of joints between panels and connections to structural elements were key aspects of the ability of the panels to resist fire (Collier & Baker, 2004), and it was noted that the panels performed adequately for their application. Different types of core insulation materials are also used for metal-skinned SIPs. Some of these are classified as non-combustible, which can result in different failure mechanisms under fire conditions, but only limited research is available on these products (Guinta d'Albani, 2014).

While limited research information is available on metal-clad SIPs for residential applications, there are examples of these being used in New Zealand. Site visits by BRANZ researchers in recent months provided examples of stand-alone residential buildings constructed with these types of SIPs, and plasterboard encapsulation was used as a means of achieving adequate fire resistance, similar to SIPs with a timber-based face layer.

2.1.3 Cement-based board

Another material being used as a face layer for SIPs in New Zealand is magnesium oxide (MgO) board, which is a relatively new material to the construction industry, both in New Zealand and internationally. MgO boards are typically produced from an MgO-based cement and filler materials such as wood and perlite and include a reinforcing mesh for strength (Aiken et al., 2020). In New Zealand, MgO boards are used in both interior and exterior applications, including as sheathing, internal linings, rigid wall underlays, cladding and as face layers in SIPs.

The ICC-ES provides testing and validation procedures for recognising the use of MgO-based boards within the IBC and the IRC through the use of ICC-ES AC386 *Acceptance criteria for fiber-reinforced magnesium oxide-based sheets*. The scope of AC386 includes MgO-based sheets for use as wall sheathing and floor underlayment and does not specifically include their use as face layers for SIPs. AC386 refers to ASTM E119 *Standard test methods for fire tests of building construction and materials* for fire-resistance testing and to ASTM E136 *Standard test method for assessing combustibility of materials using a vertical tube furnace at 750°C* for assessing the combustibility of the MgO boards. The British Standards Institute has recently published a publicly available specification for the testing and validation of MgO boards in some applications. PAS 670 *Magnesium oxide-based boards for use in buildings – Specification* was developed in conjunction with the UK Magnesium Oxide Building Board Trade Association to address concerns related to the performance of MgO boards in high-humidity environments. Within PAS 670, reaction-to-fire properties are determined in accordance with BS EN 13501-1 *Fire classification of construction products and building elements – Classification using data from reaction to fire tests*.

The fire resistance of MgO boards is cited by manufacturers and suppliers as a key advantage of the material. However, limited research has investigated the performance of MgO boards in a fire scenario. Research into the behaviour of MgO SIPs with an EPS core under fire conditions showed that, at different stages of the fire, different temperature-related processes dominate the failure of the MgO-based SIP (Bolanos Cuevas, 2019). In the early stages of a fire, heat conducted through the MgO boards was enough to cause the EPS beads to contract. In this pre-flashover phase, the reduction of strength of the SIP system was mainly a result of separation between the face and core layers whilst the strength of the MgO board itself was unaffected. At temperatures representing fully developed fire conditions, the structural loadbearing capacity of the MgO board became compromised before layer separation occurred.

Although not related to their use in SIPs systems, fire tests on MgO board-lined light-gauge steel framing found that cracks occurred in the MgO board due to dehydration reactions (mass loss) and bowing of the board (Rushti, Ariyanayagam, Mahendran & Poologanathan, 2017). The findings suggested that the amount of chemically bound water in MgO boards will affect fire performance by reducing mechanical properties and increase panel deflections and that performance can be enhanced by reducing the water content. However, because chemically bound water can act as a heat sink and therefore enhance thermal performance, the desired balance between thermal and mechanical performance should be considered when deciding water content.

2.2 Core materials

The core component of a SIP is a rigid material that provides insulation and structural support by distributing load between the face layers. Core materials are typically rigid foams made of either EPS, XPS, PUR or PIR.

The type of insulation material used differs between SIP manufacturers, as different insulation materials offer advantages and disadvantages. Consideration is given to factors such as the cost, thermal performance, density and manufacturing method required to join the foam to the face layers of the SIP. In the case of EPS and XPS, the core is joined to the face layers using a structural adhesive. PUR and PIR are injected between the face layers as a liquid, and they are joined through self-adhesion.

2.2.1 Expanded polystyrene (EPS)

EPS foam is a thermoplastic material. Thermoplastics can melt without degrading when heated above a characteristic melting temperature and solidify when subsequently cooled while sustaining no irreversible changes to their chemical structure. EPS is made from fused beads of polystyrene that have been expanded using a blowing agent, typically pentane, into the desired product shape (Sulong, Mustapa & Rashid, 2019). EPS in New Zealand is manufactured in accordance with AS 1366.3 *Rigid cellular plastics sheets for thermal insulation – Rigid cellular polystyrene – moulded (RC/PS-M)*, which categorises EPS into one of six classes according to its physical properties, largely determined by its density. Commonly available classes of EPS for insulation applications are S and H, which have nominal densities of 16 and 24 kg/m³ respectively (Cox-Smith, 2004).

Without the use of flame retardants, EPS is an inherently combustible material that begins to soften and melt at around 100°C, due to the collapse of the EPS beads. This can cause the EPS core to shrink away from the face layers and affect the structural properties of the SIP system (Bolanos Cuevas, 2019). At around 350°C, EPS produces ignitable gases, and ignition can occur when initiated with a pilot flame. Once ignited, molten EPS will pool at the floor level in the case of wall SIPs (Collier, 2005).

In practice, the fire behaviour of a given EPS product is determined by how the product is used and its physical properties. The reaction of EPS to fire can be modified by using a flame-retardant additive during the manufacturing process, which is commonly the case for EPS available in New Zealand. In a SIP with EPS bonded to the face layers with an epoxy resin adhesive, the fire performance of the EPS was improved by incorporating an intumescent flame retardant into the adhesive (Li et al., 2022). The piloted ignition temperature for flame-retardant treated polystyrene typically increases from 350°C to 430–445°C (Collier, 2005). The behaviour of the EPS core of a metal-skinned insulated panel when exposed to radiant heat was studied by Baker (2002). It was found that flame-retardant EPS would not support self-sustaining fire spread inside the insulated panel when the core was exposed to a direct radiant heat source.

2.2.2 Extruded polystyrene (XPS)

XPS foam has similar fire performance characteristics to EPS but it is manufactured differently. XPS is formed by melting solid polystyrene with additives and a blowing agent. The liquid is then extruded through a die under controlled temperature and pressure conditions and enabled to expand into the desired shape as it cools. The continuous extrusion process results in XPS having a uniform closed-cell appearance with no voids, whereas EPS has a visibly cellular structure. At a given thickness, XPS has a greater insulation performance than EPS but is more expensive. Therefore, XPS tends to be used less commonly than EPS for general insulation applications (Cox-Smith, 2004).

2.2.3 Polyurethane (PUR)

PUR is a widely used material that is available in a variety of forms, including as an elastomer, coating and flexible and rigid foams (Gama, Ferreira & Barros-Timmons, 2018). PUR foams are widely used in the construction industry as insulation materials due to their low thermal conductivity. Rigid PUR foam has a long history of use in New Zealand as a core component of SIPs in commercial applications such as in refrigeration or cold stores and more recently as a component in SIPs for residential applications.

Rigid PUR foam is made from the polymerisation of two main components – polyalcohols and polyisocyanates. A blowing agent (typically pentane or water) is used to expand the polyurethane into the desired foam structure, and other additives may be used as desired. The ratio of the ingredients in the polymer and chosen reaction process contribute to the range of properties PUR materials can have.

Along with other polymer foams, PUR is a good insulation material because of its low thermal conductivity and low density. From a fire performance perspective, these properties mean that the temperature of PUR will rise rapidly compared to more dense and thermally conductive materials when exposed to a given heat flux (Günther, Lorenzetti & Schartel, 2018). As opposed to polystyrene foams, which are thermoplastics, PUR foams are thermosets that decompose at high temperatures without melting, often forming char (McKenna & Hull, 2018). Rigid PUR foams have been found to decompose between 200°C and 410°C and produce yellow smoke up to around 600°C. At temperatures above 600°C, the yellow smoke decomposes to produce a range of nitrogen-containing compounds – the most abundant of which is hydrogen cyanide.

PUR foams have received much attention from the fire research community in an effort to understand and manage the risks associated with their use (McKenna & Hull, 2016; Günther et al., 2018). As with polystyrene-based insulation, the fire behaviour of a given PUR product will depend on its physical properties, including whether its composition includes fire-retardant additives.

Polyisocyanurate (PIR) is a subset of PUR foam that includes substantial polyisocyanurate content created during the polymerisation process. PIR is potentially more thermally stable than PUR due to a higher degree of cross-linking, which may result in better reaction-to-fire properties.

2.2.4 Other materials

Polymer foams are the most commonly used core materials in SIPs, both in New Zealand and overseas. However, some alternative materials are also used or have been investigated. These materials are often considered as having potentially lower embodied carbon products than the petrochemical-based foams described above. Examples include mineral wool and bio-based materials such as straw, cellulose-based foams (McIntosh & Harrington, 2007) and fibreboards including cellulose nanofibres (Kojima et al., 2021).

3. SIP building systems

SIP building systems are different to New Zealand's traditional light timber-framed construction, although the completed buildings may look similar. Across the range of SIPs available in New Zealand, systems can differ from one another in the way the panels are connected and other construction details. SIP suppliers typically provide technical guidance that is specific to their proprietary system. As with traditional construction types, other aspects of the building system will influence the fire performance of a SIP building. Examples include the lining materials, cavities, claddings, penetrations, joints and fixings as well as the building design and ventilation systems.

As noted in the previous sections, it is important to understand the fire performance of the components comprising SIP systems, but it is also important to understand the behaviour of SIP systems as installed in buildings as part of a completed and integrated system. SIPs are often part of systems including linings and can be encapsulated with other materials, therefore making a system test for fire performance even more important. This system is somewhat analogous to light timber-framed building systems, which are most often tested in this way. In New Zealand, testing according to AS 1530.4 *Methods for fire tests on building materials, components and structures – Part 4: Fire-resistance tests for elements of construction* is often used to determine the fire resistance rating for wall and floor assemblies, and this would be applicable for SIP constructions. Lining SIPs with a fire-resistant plasterboard typically provides 30-minute fire resistance to a SIP wall regardless of the type of SIP (BM TRADA, 2011). More detail on the fire testing and evaluation of SIPs is provided later in this report.

The connection between SIP panels is important for maintaining the structural integrity of the building system, including during a fire scenario. Examples of connections between SIP panels with timber-based face layers include dimensional timber or laminated veneer lumber (LVL) splines, foam block or mini-SIP splines and OSB splines (Figure 1).

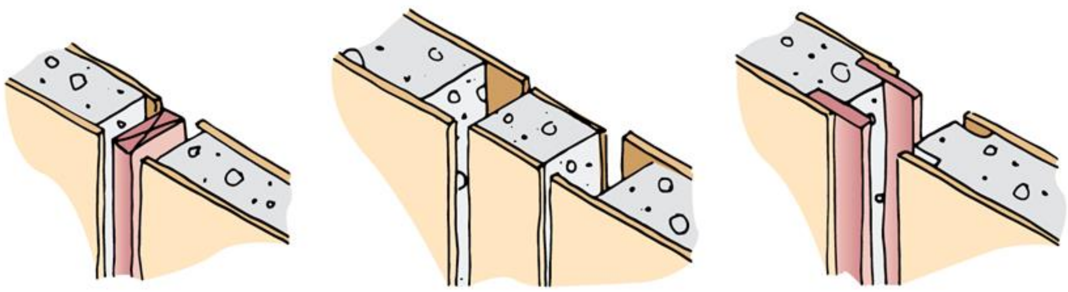

Figure 1. Examples of connections between SIPs – dimensional timber or laminated veneer lumber (LVL) spline, foam block or mini-spline and OSB thin spline.

These can be similar for steel and cement-based face-layer SIPs, but different SIP manufacturers use different connection techniques, and these systems all have the potential to perform differently during a fire (Rungthonkit, 2012). In some cases, the connections can include combustible materials and may also include a range of fasteners, including some SIPs that use locking cam mechanisms to connect panels to one another.

In some SIP walls, the connections between panels have the potential to enable the early penetration of heat into the panel interior, thereby short-circuiting the outer face protection and involving the core prematurely. The connection and spline details are important for maintaining the structural integrity of the assembled wall. If these internal members are full height, they can also be used for loadbearing once the exposed face layers become damaged. The internal joints are exposed to high temperatures in two situations: at the beginning of the fire, through the gap formed between the boards at the panel junction, and at the later stage of the fire, because part of the wall becomes damaged and the core degradation develops horizontally behind the outer facings. Whilst the exposure of the joint through the board gap at panel junctions cannot be avoided, the second type of exposure can be lessened by a fire-resistant core substrate and enhanced board restraint (Bregulla, 2003).

The use of flammable core materials in composite panels like SIPs creates the risk of them becoming involved in a building fire. If the facings are secured to the core with no through-fixings, there is a risk that the panels will collapse early and cause accelerated flame spread (Collier & Baker, 2004). However, if panel facings remain secured and joins remain tight, there should be no unexpected sudden spread of flame across a wall or ceiling.

Internal LVL or timber studs, rafters and joists are used within some SIPs to provide structural support. In a fire scenario, the effect of internal members on the temperature reaction of SIP walls depends on the stage of the face-layer degradation. Internal studs do not impede or delay the shrinkage related to through-depth cracking and therefore do not enhance the shielding ability of the face-layer material. Although timber-based face layers exhibit different decomposition behaviour than MgO-boards, the inclusion of studs is similarly ineffective in the initial reaction stages of the wall. In the post-shrinkage stage of the board degradation, internal studs help to support and restrain the dehydrated and cracked board pieces and thereby slow down the heat exposure of the interior parts of the panel (Bregulla, 2003).

3.1 Top and bottom plates

Very similar to typical light timber-framed walls, there are often two LVL or solid timber members running along the top and bottom of the SIP panels called top and bottom plates, respectively (Figure 2).

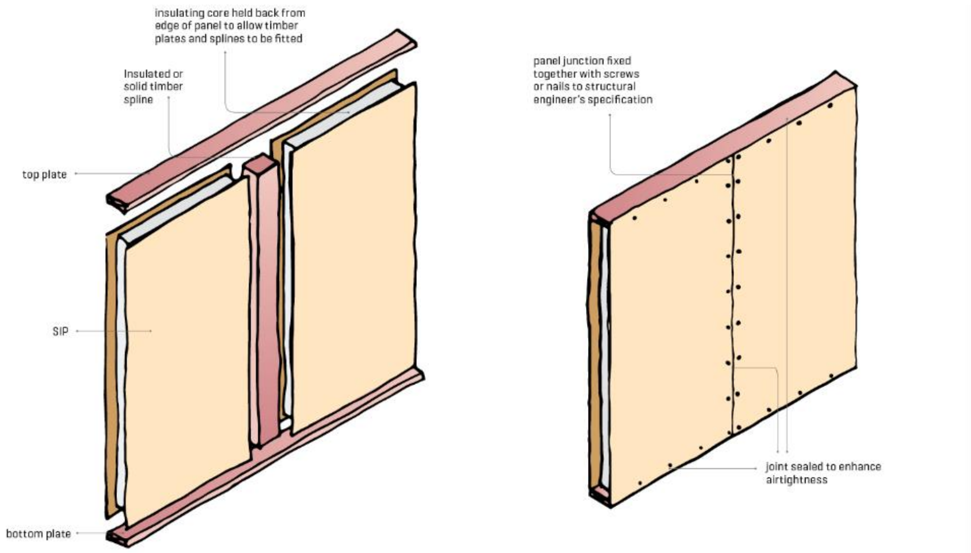

Figure 2. Typical timber-based face layer SIP wall assembly.

These plates allow the wall SIPs to be connected to the roof, ceiling or floor systems, which may or may not be a SIP themselves. The depths of the plates are the same as the rebated grooves at both ends of the SIP and are therefore protected by the SIP skins. Top and bottom plates are typically fixed to the SIP using nails or screws in the case of timber-based face-layer SIPs, through the face layers and into the plates.

A sole plate can be used to support the panel by bolting through the base and attaching to the bottom plate. SIPs are usually used with platform construction to construct the structure where the wall panels support the floor elements to create a platform and subsequent floors are built on the platform. The plates are used to connect the wall panels to horizontal panel elements and to connect single panels along the top and bottom horizontal edges. The bottom plate can also be used as the connection between the wall SIPs and the foundation. Gaps in walls between bottom and sole plates can affect breakage and premature failure (Bregulla, 2003).

Research across a range of SIP types and materials has suggested that the properties of the constituent materials comprising the SIPs are important in determining the fire resistance properties of SIPs for use in construction. It has also been suggested that full-scale testing of completed SIP systems, as they would be installed within buildings, is crucial to understand the implications of connection and construction methods on the fire resistance of SIP buildings. Methods have been proposed (Bregulla, 2003) for using a range of small, mid-scale and full-scale testing to evaluate SIP system fire performance. By understanding the range of performance provided by these systems, designers can determine the ability of SIPs to provide adequate resistance to heat and fire as required by applicable building codes.

3.2 Other considerations

SIPs buildings typically achieve a high level of airtightness (Cardoso et al., 2018), are more insulated than traditional New Zealand light timber-framed buildings and require mechanical ventilation systems to ensure adequate ventilation. The effect of these building performance features on fire behaviour has been studied although not specifically on SIP constructions. For example, modelling of fire behaviour inside houses built to Belgian Passive House levels showed that interior oxygen levels reduced significantly when a fire occurred and highlighted the importance of fast evacuation (Debrouwere, 2012). Reduced oxygen levels meant that the fire would self-extinguish if all building openings were closed. A build-up of combustion gases was found to cause internal pressure to increase, which could hinder the operation of inward-opening doors. Similarly, full-scale fire experiments of an airtight building found that internal pressure was greater when mechanical ventilation inside the compartment was off (ducts closed) compared to when it was on. Even with mechanical ventilation on, there was a risk of overpressure, which could hinder the operation of inward-opening doors for a short period of time (Brohez & Caravita, 2018). This could have implications for occupants trying to escape and firefighting operations (Hume, 2004).

Other studies have looked at the impact of airtightness on temperature variability and concentration of toxic gases (Gałaj & Saleta, 2020a, 2020b). Concentrations of all toxicants measured except nitrogen dioxide (NO_2) were found to be greater in a sealed compartment compared to an unsealed one with a window open. Lower oxygen levels were found in the sealed compartment compared to the unsealed one.

4. Regulatory requirements

SIP buildings must meet the fire safety requirements of relevant building regulations, which may include specific provisions for SIPs or not. This section considers the types of fire safety requirements applicable to SIP buildings in a selection of countries where they are known to be used. In some cases, where SIPs have a longer history of use, they are specifically considered in building codes. However, in other countries, including New Zealand, there are no specific provisions for SIPs.

4.1 New Zealand

SIP buildings must comply with all relevant requirements of the New Zealand Building Code (NZBC), including the six C clauses, which relate to protection from fire. In all current NZBC protection from fire compliance documents, there are specific reaction-to-fire requirements for building systems, which include foamed plastic or combustible insulation. All SIPs that include these products would be subject to these requirements. Depending on the application and building configuration, a specific SIP element may also require a fire resistance rating (FRR).

4.1.1 Foamed plastics

In all cases, foamed plastic needs to comply with AS 1366 flame propagation criteria. There are four parts to the standard, each covering a different type of foamed plastic:

- AS 1366.1 – rigid cellular polyurethane
- AS 1366.2 – rigid cellular polyisocyanurate
- AS 1366.3 – rigid cellular polystyrene – moulded
- AS 1366.4 – rigid cellular polystyrene – extruded

The flame propagation criteria vary for each type of plastic and are based on test results from AS 2122.1 *Combustion characteristics of plastics – Determination of flame propagation – Surface ignition of vertically oriented specimens of cellular plastics*. Test specimens have dimensions of 255 mm x 20 mm x 20 mm and are exposed to a Bunsen burner flame. Criteria include median and eighth values for both flame duration and volume retained, based on sets of 10 test repetitions. For thermoplastics, flame duration and volume retained are determined using two separate sets of experiments.

While it is possible to assess system performance through desktop calculations, it is often more effective to conduct full-scale fire performance testing to determine the FRR for a specified building assembly and obtain more-reliable results. This is often due to the interaction between components – and in particular, the connections and panel joints used to encapsulate combustible core materials. These panel edge details were also highlighted by Collier and Baker (2004) as being critical for the fire performance of insulated panels when tested in room-scale fire tests, further suggesting that small-scale testing would not provide a full picture of SIP fire performance.

In general, small-scale tests have been found to be unreliable for evaluating the fire risk associated with foamed plastics. This led to the development of the room corner tests such as ISO 9705-1 *Reaction to fire tests – Room corner test for wall and ceiling lining products – Part 1: Test method for a small room configuration* (Williamson & Mowrer, 2004). Foamed plastics tend to melt away from the small heat sources in small-scale fire tests and self-extinguish. When faced with a larger, growing heat source at room scale, sustained ignition and rapid fire growth can occur.

Research was conducted by Van Hees and Johansson (2001a, 2001b) on metal-skinned SIPs with different core materials. These researchers used two approaches. They first tested to ISO 9705 and then used a modified method where a free-standing SIP room was built under a large calorimeter instead of having an exhaust hood at the doorway of the ISO 9705 compartment. This full-scale work concluded that joint detailing is an important factor in the fire behaviour of insulated panels. Fire behaviour of the panels was acknowledged as being the result of material characteristics and the mechanical behaviour of the panels such as joints and openings. It was further concluded that simulating the end-use conditions in a realistic way is very important when evaluating the fire performance of sandwich panels.

NZS 4541 *Automatic fire sprinkler systems* sets out requirements and includes provisions for buildings built with expanded plastic cored insulated panels. This includes options for laboratory-approved panels and non-laboratory-approved panels. Laboratory-approved panels include those tested and approved by accredited laboratories to one of the following:

- ISO 13784 *Reaction to fire tests for sandwich panel building systems.*
- FMAPPROVAL 4880 *Evaluating the fire performance of insulated building panel assemblies and interior finish materials.*
- LPS 1181 *Series of fire growth tests for LPCB approval and listing of construction product systems* – Part 1 or Part 2.
- LPS 1208 *LPCB fire resistance requirements for elements of construction used to provide compartmentation.*
- ISO 9705-1.

The following criteria are listed for panels tested to ISO 9705-1:

- They do not support a self-propagating fire that extends to the outer extremities of the test area within the 20-minute test as evidenced by flaming or material damage when the lining is removed (including melting or charring of core materials).
- They do not reach flashover (total heat release of 1000 kW) when exposed to 100 kW for 600 seconds followed by exposure to 300 kW for 600 seconds.
- They have a smoke growth rate index ($SMOGRA_{RC}$) not more than 100.
- They sustain the applied load, if any, for the duration of the test period.

NZS 4541 Table 2.8 sets out sprinkler system requirements that must be complied with when non-laboratory-approved foamed plastic cored insulated panels are present. These requirements depend on panel thickness and density and include sprinkler spray density, sprinkler system type and perimeter sprinkler characteristics. Panels that have been laboratory approved to achieve all of the above criteria are not required to comply with Table 2.8. Further explanation of requirements for foamed plastic cored insulated panels are given in Appendix K of NZS 4541.

Additionally, in most cases, building elements including foamed plastics or combustible insulation also require a Group Number that takes the entire building element into consideration. Group Numbers can always be determined through the use of an ISO 9705 test. ISO 13784.1 can also be used and is particularly relevant for SIPs construction, although no capacity to test using this standard currently exists in New Zealand. As with the AS 1530.4 fire resistance test standard, the version referenced by the NZBC compliance documents at the time of publication are not the most recent version. With the use of these tests, the Group Number is determined as follows:

- Group 1: 1 MW total heat release rate (HRR) including contributions from the test specimen and the burner, is not exceeded before 20 minutes.
- Group 2: 1 MW total HRR is exceeded between 10 and 20 minutes.
- Group 3: 1 MW total HRR is exceeded between 2 and 10 minutes.
- Group 4: 1 MW total HRR is exceeded before 2 minutes.

Cone testing to ISO 5660-1 *Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)* or AS/NZS 3837 *Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter* can also be used to determine Group Numbers for some materials, including those used for SIP lining materials. However, as the full element is generally required to be considered when foamed plastics or combustible insulation products are included, this will not always be an option. Exceptions as per Appendix A of Verification Method C/VM2 include:

- if the test laboratory is satisfied that the surface lining is sufficiently robust and well fixed such that the substrate materials are unlikely to influence the outcome of the Group Number classification or
- foamed plastics or combustible insulating materials that form part of an element requiring a Group Number can be assumed not to influence the Group Number classification and need not be included in the test specimen if:
    - the surface lining material is a rigid sheet product of gypsum plasterboard, plywood, solid wood, wood composite, fibre-reinforced cement, concrete or masonry and is not less than 9mm thick
    - it is securely fastened with steel fasteners to a conventional lightweight timber or steel frame or concrete/masonry wall
    - all sheet joins are supported and sealed and/or stopped with a non-flaming material.

In all cases, metal-skin SIPs assemblies with combustible core materials require testing to ISO 9705 or ISO 13784.1 to determine a Group Number classification.

4.1.2 Requirements for different building types

Acceptable Solution C/AS1 can be applied to low-rise stand-alone or multi-unit dwellings where each unit is independent of all other units (classified as risk group SH). C/AS1 requires that wall systems that include foamed plastics or combustible insulation shall achieve a Group Number of not more than 3, which would apply to SIPs with a foamed plastic core. There are no other surface lining requirements in C/AS1 for the SH risk group. SIPs used in locations required to be a fire separation such as inter-tenancy walls or for external walls close to a boundary may also require a 30-minute FRR in SH buildings. As in Australia, fire resistance is tested using AS 1530.4. Note that the version of AS 1530.4 referenced in the NZBC protection from fire compliance documents at the time of publication is 2005, not the most recent version.

For higher-risk construction types such as multi-unit residential, commercial or education buildings, additional fire safety requirements apply depending on the building typology. Acceptable Solution C/AS2 or Verification Method C/VM2 can be used to determine fire requirements for the building types not covered by C/AS1. These include risk group SM buildings or multi-unit residential buildings with a shared means of escape. Similar to C/AS1, fire resistance ratings are required where wall or floor elements are required to act as fire separations or for external walls depending on proximity to a boundary. The required FRR for residential buildings in C/AS2 depends on whether the building is sprinklered (30 minutes required) or unsprinklered (60 minutes required). FRRs required under C/VM2 require evaluation by a fire safety practitioner. Group Number requirements for higher-risk buildings are included in NZBC clause C3.4(a), as shown in Figure 3.

PERFORMANCE

C3.4 (a) materials used as internal surface linings in the following areas of *buildings* must meet the performance criteria specified below:

Clause C3.4 does not apply to *detached dwellings*, within *household units* in *multi-unit dwellings*, or *outbuildings* and *ancillary buildings*.

Area of *building*	**Performance determined under conditions described in ISO 9705: 1993**	
	***Buildings* not protected with an automatic *fire* sprinkler system**	***Buildings* protected with an automatic *fire* sprinkler system**
Wall/ceiling materials in sleeping areas where care or detention is provided	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in exitways	Material Group Number 1-S	Material Group Number 1 or 2
Wall/ceiling materials in all *occupied spaces* in importance level 4 *buildings*	Material Group Number 1-S	Material Group Number 1 or 2
Internal surfaces of ducts for *HVAC systems*	Material Group Number 1-S	Material Group Number 1 or 2
Ceiling materials in crowd and sleeping uses except *household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1 or 2
Wall materials in crowd and sleeping uses except *household units* and where care or detention is provided	Material Group Number 1-S or 2-S	Material Group Number 1, 2, or 3
Wall/ceiling materials in occupied spaces in all other locations in *buildings*, including *household units*	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3
External surfaces of ducts for *HVAC systems*	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3
Acoustic treatment and pipe insulation within airhandling plenums in sleeping uses	Material Group Number 1, 2, or 3	Material Group Number 1, 2, or 3

Figure 3. Group Number requirements in NZBC clause C 3.4(a).

Some New Zealand SIP suppliers have third-party verification that demonstrates compliance with specified NZBC requirements within a specified scope of use. These include systems with BRANZ Appraisals and CodeMark. Not all relevant NZBC aspects may be included in the scope of these verification documents. This includes fire safety requirements, particularly when they are dependent on the application. As they do not generally describe what is not in scope, care must be used when employing these verification systems to establish NZBC compliance.

4.2 USA

The International Code Council adopted SIPs into the IRC in 2007. The IRC provisions are for SIPs used as loadbearing walls in residential buildings up to two storeys high and include allowable wind and snow loads as well as seismic design categories of the site. In those jurisdictions where the IRC applies, SIP walls designed using the provisions set out in IRC section 610 do not require an additional engineering assessment to demonstrate compliance.

The IRC requires that SIPs comply with the requirements of ANSI/APA PRS 610.1, which sets minimum material properties, structural capacity and construction detailing that manufacturers must comply with in North America. The fire performance requirements of ANSI/APA PRS 610.1 are shown in Table 1 below.

IRC section R610.5.6 specifies that SIPs with foamed plastic insulation shall be separated from the interior of a building by an approved thermal barrier in accordance with IRC requirements for foam plastics (section 316.4). These requirements state that foam plastics shall be separated from the interior of a building by an approved thermal barrier of not less than ½ inch (12.7 mm) gypsum wallboard or 23/32 inch (18.2 mm) wood structural panel or a material that is tested in accordance with and meets the acceptance criteria of both the integrity fire test and the temperature transmission fire test of NFPA 275 *Standard method of fire tests for the evaluation of thermal barriers* (see Table 1).

ICC-ES AC04 provides a means for sandwich panels to be recognised under the US-based building codes and includes the following fire performance requirements:

- Panel facings exposed to the building interior shall have flame-spread and smoke-density ratings as specified in IBC section 803.1 and IRC section R315. Plastic materials shall be approved plastics as set forth in IBC section 2602.1 and 2606.4 for use under the IBC or IRC.
- Core materials classified as non-combustible shall be justified under IBC section 703.4 and IRC section R202. Combustible core materials, except foam plastic, shall have a minimum Class III flame-spread classification not exceeding 200 and smoke-density rating not exceeding 450 when tested under ASTM E84 for use under the IBC and IRC. Foam plastic cores shall comply with IBC sections 2602.1 and 2603 and IRC section R314 and the ICC-ES acceptance criteria for foam plastic insulation.

The SIPA website contains a series of technical bulletins for SIPs, including one about the topic of complying with IBC fire safety requirements (SIPA, 2011) and one addressing the use of flame retardants in polystyrene insulating cores (SIPA, 2012).

Table 1. International Residential Code (IRC) fire safety requirements for SIPs.

IRC requirement	Referenced standard	Test method(s)	Acceptance criteria
SIPs shall comply with requirements of ANSI/APA PRS 610.1	ANSI/APA PRS 610.1	ASTM E84 or UL 723 *Standard for test for surface burning characteristics of building materials*	For SIPs with core materials excluding foam plastics: • Core material must have a flame spread index ≤75 and smoke-developed index ≤450 when tested in accordance with ASTM E84 or UL 723 at 4 inches thickness. For SIPs with foam plastic insulation ≤4 inches (102 mm) thick: • Flame spread index ≤75 and smoke developed index ≤450 when tested in the maximum thickness and density intended for use in accordance with ASTM E84 or UL 723.
Foam plastics shall be separated by an approved thermal barrier (IRC section 316.4 for foam plastics)	NFPA 275	Temperature transmission fire test	• During the 15-minute test period, the average measured temperature rise of the thermocouples shall not exceed 250°F (139°C). • The measured temperature rise of any single thermocouple shall not exceed 325°F (181°C).
		Integrity fire test (in accordance with one of: • NFPA 286 *Standard methods of* fire *tests for evaluating contribution of wall and ceiling interior finish to room fire growth* • FMAPPROVAL 4880 • UL 1040 *Fire test of insulated wall construction* • UL 1715 *Fire test of interior finish material*	Conditions of acceptance for tests conducted in accordance with FMAPPROVAL 4880, UL 1040 or UL 1715 shall be as specified in the standard used. For tests conducted in accordance with NFPA 286, the following acceptance criteria apply: • No flame spread to the ceiling during 40 kW fire exposure. • No flame spread to the outer extremity of the test assembly on any wall or ceiling. • Flashover shall not occur. • Peak heat release rate shall not exceed 800 kW. • Total smoke released shall not exceed 100 m^2.

4.3 UK

SIPs with OSB face layers have been used in the UK for several decades, and their popularity was reflected in the establishment of the trade association UKSIPS, which merged with the Structural Timber Association (STA) in 2014. While SIPs are not explicitly considered in UK building regulations, STA provides a series of technical bulletins on designing and building with SIPs, including one on fire (BM TRADA, 2014). This includes general guidance for SIP buildings to comply with national building regulations. Similar guidance has also been published by BM TRADA, which provides independent guidance on best practice design, specification and use of wood in the built environment. The information sheet (BM TRADA, 2020) includes an overview of the fire performance considerations with SIP construction. It states that SIPs will be able to meet given building regulations as long as they are designed, manufactured and installed correctly. A summary of the key points from these technical bulletins is provided in Table 2.

Table 2. Summary of guidance from SIP technical bulletins published by STA and BM TRADA (BM TRADA, 2014, 2020) for SIPs buildings in the UK.

Building element in SIPs construction	Guidance
Internal walls	Non-loadbearing: • If fire resistance is required, it can typically be provided by wall linings – for example, 15 mm plasterboard will achieve a 30-minute fire resistance. Loadbearing: • Fire resistance of 30 or 60 minutes is usually required and can be achieved by one or two layers of 15 mm plasterboard respectively.
External walls	• Fire resistance is provided by wall linings that are typically plasterboard or other fire-resistant board. • Typically, one layer of 15 mm fire/high-temperature plasterboard fixed to timber battens will provide 30-minute fire resistance to a SIP wall regardless of the type of SIP or core insulation material.
Inter-tenancy (party) walls	• Typical fire resistance required is 60 minutes for intertenancy walls in buildings up to 6–7 storeys. • SIP inter-tenancy walls normally consist of two separate SIP walls separated by a cavity. • Fire resistance can be achieved using plasterboard linings. The SIP manufacturer should be asked to provide plasterboard specifications for SIPs used as party walls. • Ideally, services that penetrate plasterboard linings should not be installed on intertenancy walls, and some national building regulations prevent this.
Floors	• Fire resistance is provided by using plasterboard linings of the required thickness.
Roofs	• Generally, do not require specified fire resistance ratings unless roof structure is part of an escape route or the roof void is a habitable space. • If roof forms part of an escape route, fire resistance requirements should be considered on a project-specific basis. • If roof void forms a habitable space, fire resistance can typically be provided using plasterboard.

Building element in SIPs construction	Guidance
Cavity barriers	• Cavity barriers are designed to limit the spread of smoke and fire through cavities or concealed spaces. • Cavity barrier requirements may vary between building regulations. All regulations in the UK require that edges of cavities are closed and that cavity barriers are used at compartment wall junctions and compartment floor junctions with external or other compartment walls. • Cavity barriers must be installed onto solid timber (e.g. studs around window openings or header joists at floors) to ensure that fire is not able to bypass the cavity barrier within the foam core of the SIP.
Boundaries	• Fire resistance of either 30 or 60 minutes may be required if the building is constructed within 1 m of a boundary. • Cladding may provide adequate fire resistance (e.g. if masonry).

Currently, combustible materials are not allowed in external walls under UK building regulations for "relevant buildings" over 18 m in building height.[3] Relevant buildings include all buildings containing dwellings, including residential buildings. Insulated core panels have specific requirements when used internally. These include:

- panels should be sealed such that the core is not exposed to fire, including at joints and service penetrations
- only non-combustible (class A1) panels should be used in high fire risk areas such as kitchens
- delamination of panels should be accounted for in the panel fixing system.

4.4 Australia

Several different SIP systems are manufactured and supplied across Australia, including some that have received CodeMark or similar third-party verification of their performance against selected Australian building code requirements. SIPs are not specifically included in Australian building regulations and so testing and certification is advised to ensure that products meet the necessary fire safety requirements.

Australia's National Construction Code (NCC) section C *Fire resistance* classifies construction into three types (A, B and C) according to fire resistance. SIPs with combustible insulation or face layers would not be permitted for type A or B constructions, which are typically for higher-risk buildings above 2–3 storeys. SIPs with combustible components would be allowed for type C construction, which is generally only allowed for buildings of 1–2 storeys depending on the building classification.

Timber can be allowed up to 25 m building height, but it has to be "fire protected" (incipient spread of fire test or 2 x 13 mm fire-protective grade plasterboard protection) and with no combustible insulation. Alternative solutions may be possible.

The fire resistance test AS 1530.4 is used in both Australia and New Zealand, although there may be variation in the versions of the standard adopted in different jurisdictions.

[3] https://www.gov.uk/government/publications/fire-safety-approved-document-b

5. Summary

Construction using SIPs has been suggested as one possible solution to New Zealand's urgent need for fast, affordable and quality homes. Although they have been used in some countries for several decades, SIPs for residential construction have a relatively short history of use in New Zealand, and therefore little information is available about their performance in a local context. This report has considered the fire performance of SIPs based on overseas and New Zealand literature at both a material and building level to understand their behaviour and suitability for use within the local compliance regulations.

This report highlights that SIPs can be manufactured with a range of materials for both the core and face-layer components and that the choice of materials can influence the behaviour of the system in reaction to fire. Similarly, SIP systems can be configured using different connections and assembly methods, which can also affect fire performance of the buildings using them. SIPs with timber-based face layers are used most commonly internationally for residential construction, and considerable work has been done overseas to investigate and manage their fire safety. In countries where SIPs have been used for several decades, guidance documents have been developed that suggest SIPs buildings can meet fire safety regulatory requirements with the use of suitable lining materials, where specific fire resistance ratings are specified. The inclusion of SIPs in some building codes further indicates confidence in their use in those jurisdictions.

Much of the overseas information and documentation is relevant to the New Zealand setting, although some specific tests are likely to be required to ensure that systems comply with local regulations. The type of building will determine what fire performance requirements apply. Different fire safety requirements will apply for various SIPs building components depending on the building typology, usage and occupancy.

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